Graduate Theses, Dissertations, and Problem Reports

2016

Evaluating Reforestation Success on Reclaimed Coal Mines in West Virginia and Determining the Release of Nutrients in Overburden Materials

Kara Dallaire

Evaluating Reforestation Success on Reclaimed Coal Mines in West Virginia and Determining the Release of Nutrients in Overburden Materials

Kara Dallaire

Thesis submitted
to the Davis College of Agriculture, Natural Resources and Design
at West Virginia University
in partial fulfillment for the requirements for the degree of

Master of Science

In

Plant and Soil Science

Jeff Skousen, Chair, Ph.D
Louis McDonald, Ph.D
Jamie Schuler, Ph.D

Division of Plant and Soil Science

West Virginia University
Morgantown, WV

2016

Keywords: reclamation, brown sandstone, gray sandstone, compaction, soil amendments, tree volume, Forestry Reclamation Approach, BCR sequential extraction

Abstract

Evaluating Reforestation Success on Reclaimed Coal Mines in West Virginia and Determining the Release of Nutrients in Overburden Materials

Kara Dallaire

Coal mining remains an important industry in West Virginia and mining operations drastically disturb the forested landscape. After mining operations, reforesting the land provides economic and ecological benefits. In order to promote successful reforestation, the Appalachian Reforestation Initiative supports the Forestry Reclamation Approach (FRA). The FRA recommends creating a suitable rooting medium and ensuring that no compaction occurs. In 2005, three 2.5-ha research plots were established at the Catenary Mine in southern West Virginia. One plot was constructed with 1.2 m of brown sandstone, another with 1.5 m of brown sandstone, and the third with 1.5 m of gray sandstone. One half of each plot was compacted. Each year tree volume data and soils have been collected. Growth rates over eleven years were compared for all tree species combined, as well as for individual species: black locust, red oak, white ash, and white oak. When comparing the 1.2 m brown uncompacted plot to the compacted side, all tree species combined together, red oak, and white oak had higher growth rates at 0.62, 0.70, and 0.71 cm^3/year, respectively. For the 1.5 m brown plot, growth rates were significantly higher in the compacted side for all trees combined and white oak, at 0.70 and 0.80 cm^3/year, respectively. The 1.2 m brown compacted plot was compared the 1.5 m brown compacted plot and tree growth rates were higher in the 1.5 plot for all trees, red oak, white ash, and white oak at 0.70, 0.72, 0.70, and 0.80 cm^3/year, respectively. Soil extractable nutrient data were found to vary widely across treatments and across all years. The pH of gray sandstone ranged from 6.5 to 8.3 on both plots over eleven years. The pH for the brown sandstone plots ranged from 4.6 to 6.6 over eleven years. Percent fines increased in all treatments in eleven years and increases ranged from 2% for the gray compacted plot to 19% in the 1.2 m brown compacted and uncompacted plots. Reclamation of mine sites can be successful when proper topsoil substitutes (such as brown sandstone) are used and left uncompacted.

Another study site was established at the Birch River Mine in Webster County, WV to assess the effects of mulch and hydroseeding treatments on the growth of twelve hardwood species on gray and brown sandstone. In 2006, a 2.5-ha plot was constructed with half 1.5 m of brown sandstone and half 1.5 m of gray sandstone. Bark mulch was applied to the center of the plot covering both brown and gray substrates and each end was hydroseeded, resulting in eight treatments. Each year tree volume data and soil samples were collected. Growth rates over nine years were compared for all trees species combined, as well as black locust, sugar maple, white oak, and white pine. The brown mulch treatments were compared to the brown non-mulch treatments and all species combined and white pine had significantly higher growth rates in the mulch treatments, at 0.78 and 1.2 cm^3/year, respectively. When comparing the brown hydroseeded treatments to the non-hydroseeded treatments, all tree species combined and black locust were found to have significantly higher growth in the hydroseeded treatments at 0.72 and 0.73 cm^3/year, respectively. The gray mulch treatments resulted in significant increases for all species, black locust, white oak, and white pine over the gray non-mulched treatments at 0.79, 0.70, 0.98, and

1.12 cm^3/year, respectively. All tree species combined and white oak were had significantly higher growth rates at 0.65 and 1.00 cm^3/year, respectively, on the gray hydroseeded treatments when compared to the gray non-hydroseeded treatments. Between the gray mulch treatments and the brown mulch treatments, no significant differences were found. This indicates that the addition of bark mulch improved gray sandstone's ability to grow trees similar to brown sandstone. Soil extractable nutrient data was found to vary widely across treatments and across years. The pH of gray sandstone plots ranged from 6.4 to 8.0 over nine years. The pH of the brown sandstone plots ranged from 6.4 to 8.1 over nine years. Percent fines were increased in all the treatments in eleven years and increases ranged from 17% for the gray plot to 27% in the gray hydroseeded plot. Amendments can improve the growth rates of trees on both brown and gray sandstone and should be used in reclamation when available.

Different-aged reclaimed and abandoned areas with gray and brown sandstone at the surface were located around the Birch River Mine. Mine soils of 9, 20, and 45 years since disturbance were sampled as well as a native forest soil to determine the extractable amounts of elements in these spoils. BCR sequential extraction were performed on these samples. Nutrient availability for brown and gray sandstone was found to be highest at age 20. For P, Ca, Mg, Zn nutrient availability was found to be similar or even higher than the forest soils at age 20. Most elements decreased from age 20 to age 45 in both mine soils. By age 45, pH and organic matter content in the brown and gray sandstone were at similar levels to the forest soil.

The data from these two study sites were used to compare tree growth rates for tulip poplar (*Liriodendron tulipifera* L.), white oak (*Quercus alba* L.) and northern red oak (*Q. rubra* L.).). The height growth of each tree species on both mine sites was compared to the growth of trees on clear-cut areas at the Fernow Forest, WV. In addition, an estimated site index prior to disturbance was calculated and used to predict tree growth rates based on NRCS soil survey data. Tree heights (25 to 175 cm) on gray sandstone were significantly lower than height on brown sandstone (197 to 544 cm) for all three species. Trees on mulched plots were up to 229 cm taller than trees on un-mulched plots. Tulip poplar height on the brown treatment (544 cm) was greater than on a clear-cut area with a site index 62 at 10 years (503 cm). Tree heights on average were 50% lower on mined sites compared to heights calculated from pre-mining site indices. While the heights of trees on mine sites are increasing, the growth has not yet reached levels in the native areas.

Acknowledgments

I would like to start out my thanking my advisor, Dr. Jeff Skousen. Being able to move to the United States and study coal mine reclamation in West Virginia has been a wonderful and enriching experience and I am very grateful that he gave me this opportunity. Next I would like to thank my other committee members, Dr. Louis McDonald and Dr. Jamie Schuler. Both of you provided much needed help throughout my research. Without all her support and help in the lab, I would have not been able to complete all my lab work and for that I would like to thank Joan Wright. Next, I would like to acknowledge Dr. Ida Holaskova for spending so much time and effort running my statistical analysis.

Thank you to West Virginia University, Patriot Coal, and Arch Coal for helping to fund my research. Thank you to Jonathon Sanchez and Jeff Andrews of Patriot Coal for providing me support during my field work at the Catenary Mine site. And thank you to Keith O'Dell and Bill Young of Arch Coal for going out of their way to locate mine soils of different ages.

To all of the other graduate students, thank you for your friendship, support, and all the great memories. I wish you all the best and much success in your future. In addition, I would like to thank a very good friend of mine, Magic Hat (you know who you are), you got me through the worst of times by giving me the best of times and I would not have survived graduate school without you. And lastly, to my two lovely cats, Dennis and Mercury, you both made the long drive from Edmonton, Alberta with me and provided me with much happiness and comfort while I was adjusting to life in a new country.

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1.0 Introduction and Objectives

Coal is an important source of energy and is used to make steel and various other products (Bise, 2013). There are more than 100 minable coal seams within the Appalachians and West Virginia is the largest coal-producing state within this region (Bise, 2013; U.S. EIA, 2015). In 2013, West Virginia had 90 active surface mines that produced over 30 million Mg of coal (U.S. EIA, 2015). An estimated 1,850 million Mg of coal are recoverable by surface mining in West Virginia (U.S. EIA, 2015). Much of the coal in West Virginia is beneath a landscape which is rolling to steeply sloping and the climate in the region supports a diverse forest ecosystem. Approximately 78% of West Virginia is covered in valuable eastern deciduous forests and surface mining drastically disturbs these ecologically diverse forests. Reforestation of mined lands is important because forests provide several functions including wood and fiber production, water quality, wildlife habitat, carbon sequestration, and ecosystem stability (Burger, 1999).

The first surface mining legislation in West Virginia was enacted in 1939 (Bowling, 1978; Plass, 2000). Early reclamation scientists understood that high survival rates of tree plantings was required to ensure cover and stabilization of surface mined lands (Brown, 1962). Tree planting on mine sites had occurred since the early 1900's and research regarding this began in the 1930s (Chapman, 1947; Vogel, 1977). It is estimated that approximately 60% of land disturbed between 1930 and 1971 was reclaimed with tree or grass plantings (Keys et al., 1971). Black locust (*Robinia pseudoacacia* L.) was the most commonly planted tree, especially on sites with steep slopes (Brown, 1962; Vogel, 1977). Other species that have been successfully planted include various species of pine (*Pinus* spp.), European black alder (*Alnus glutinosa* L.*)*, tulip poplar (*Liriodendron tulipifera* L.), red oak (*Quercus rubra* L.), and autumn olive (*Elaeagnus umbellata* Thunb.) (Vogel, 1977). Success of early reclamation was attributed to the mining of shallow coal seams which resulted in replaced surface materials of mostly weathered overburden and some native topsoil (Beaty, 1967, as cited in Gorman et al., 2001).

After World War II, advancements in science and technology made it possible to surface mine coal seams that were too thin for deep mining or that were further down from the surface. These advancements caused a rapid increase in the number of acres disturbed by mining (Bowling, 1978; Plass, 2000; Plass and Powell, 1988; Skousen and Zipper, 2013). Public concern of the effects of mining on human safety and the environment increased as the total area disturbed by mining grew (Plass, 2000). During the 1940s to 1960s, more laws governing surface mining were passed that required more complete landscape restoration and revegetation of all surface mine spoils (Plass, 2000). Many hectares of mined land were successfully reclaimed to forest plantations; however, before 1977 enforcement of these laws was inconsistent across states and large areas remained unreclaimed. The Surface Mining Control and Reclamation Act (SMCRA) was enacted in 1977 by the federal government to address safety and environmental issues (Burger, 1999; Skousen and Zipper, 2013 and 2014). SMCRA caused a major change in reclamation practices (Skousen and Zipper, 2013) and emphasized that mines be reclaimed to mitigate effects from short-term hydrological impacts, sediment control, surface stability, and vegetation ground cover (Burger, 1999). Reclamation involved restoring the approximate original contour and landscape, as well as the establishment of a grass and legume cover. Fertilizer and liming treatments became accepted mine land reclamation treatments to improve the chances of success for herbaceous seeding. If trees were to be planted, it was soon observed that the aggressive herbaceous cover caused competition with tree seedlings, resulting in low tree survival. With the additional cost of planting trees accompanied by poor survival, the net effect was that tree planting almost ceased by the 1980s (Plass, 2000). This led to a huge reduction in the amount of mined lands being reforested (Burger, 1999), and the mined areas were largely reclaimed to grasslands (Zipper et al., 2011).

There are several reasons for poor performance of trees on SMCRA-reclaimed lands. SMCRA encouraged smooth grading of reclaimed land surfaces and rapid establishment of grasses and legumes to stabilize the soil and reduce erosion (Plass, 1982; Torbert and Burger, 2000). On lands reclaimed using conventional SMCRA methods, colonization of native species and natural succession to a more native-species dominated plant community are much slower (Zipper et al. 2011) because the smooth surfaces are not conducive to the recruitment and establishment of trees and other native species. During reclamation, the establishment of an herbaceous cover is easier and cheaper, and provides a protective ground cover faster than woody vegetation. Many coal mines were reclaimed as hay lands or pasture but were never used for hay or pasture by the landowners. While natural succession will eventually allow forests to be restored on these areas, the process is slow and may require decades (Angel et al., 2005; Torbert and Burger, 2000).

Over time, older mine sites, regardless of degree of reclamation, have been colonized with native plants. When no deleterious soil or water quality conditions exist, native vegetation from undisturbed plant communities will invade and establish on these sites (Skousen et al., 1994; Skousen et al., 2006; Gorman et al. 2001; Skousen and Zipper, 2013). When the physical and chemical properties of the mine soil are favorable, revegetation with planted species forms a complete ground cover and natural recolonization can gradually develop. And conversely, natural revegetation is much slower when soil conditions are less favorable and the site will be generally inhabited by only a few species (Torbert and Burger, 2000). Without proper management, lands reclaimed to hay land or pasture will eventually return to forest and with sufficient time, natural secondary succession will give rise to woody species (Skousen et al., 2006). Establishment of a commercially valuable forest on mine lands originally reclaimed to pasture is possible but the process is slow (Skousen et al., 2006).

An interest in planting more trees on reclaimed surface mines began in the 1990s (Torbert and Burger, 2000). The Appalachian Regional Reforestation Initiative (ARRI) was created to encourage restoration of high quality forests on reclaimed mines in the Eastern USA (Angel et al., 2005). ARRI promoted the Forestry Reclamation Approach (FRA) to encourage reclaiming coal mines to forest under SMCRA (Burger et al., 2005). The following five steps of the FRA are necessary for successful reforestation on mined lands:

1. Create a suitable rooting medium for good tree growth that is no less than 4 feet deep and comprised of topsoil, weathered sandstone and/or the best materials.
2. Loosely grade the topsoil or topsoil substitute established in step one to create a non-compacted growth medium.
3. Use ground covers that are compatible with growing trees.
4. Plant early successional trees for wildlife and soil stability, and commercially valuable trees.
5. Use proper tree planting techniques.

This study evaluated the use of the Forestry Reclamation Approach on surface mines in West Virginia. The growth of trees and soil characteristics was assessed on two reclaimed coal mines in West Virginia (Catenary and Birch River). The objectives of the study are described below.

- At Catenary, we assessed the growth rates of hardwood trees during an 11-year period since reclamation on the following treatments:
    - Brown and gray sandstone;
    - 1.2 and 1.5 m depth of brown sandstone; and,
    - Compacted and un-compacted brown and gray sandstone.
- At Birch River, we assessed of the growth rates of trees during a 9-year period after reclamation on the following treatments:
    - Brown and gray sandstone;
    - Brown and gray sandstone treated with bark mulch;
    - Brown and gray sandstone with hydroseed treatment; and,
    - Brown and gray sandstone treated with bark mulch and hydroseeded.
- At Birch River, we determined extractable nutrients concentrations from different-aged gray and brown sandstone materials and compare these values to a undisturbed native forest soil.

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2.0 Growth Rates of Hardwood Trees Eleven Years after Reclamation at the Catenary Mine Site

2.1 Literature Review and Objectives

The removal and salvage of topsoil on Appalachian mountainous terrain is not always possible due to thin depths and steep slopes and, under the Surface Mining Control and Reclamation Act (SMCRA), overburden materials may be substituted for topsoil if the resulting medium is equal to or better than the native topsoil. According to the Forestry Reclamation Approach (FRA), the first step in successful reclamation of surface-mined lands to forests is saving and replacing the best available overburden and soil materials for rooting media. When an appropriate material is chosen and managed properly, mine soils can often be equal to or better in tree growth than native Appalachian topsoils (Burger et al., 2005). Weathered, brown sandstones and unweathered, gray sandstones that are exposed during mining are commonly used as substitute topsoil materials (Haering et al., 2004) and are preferred over other overburden materials, such as siltstone or shales (Daniels and Amos, 1985). Brown sandstone is found closer to the surface and typically has a pH ranging from 4.0 to 5.5 due to oxidizing conditions (Haering et al., 2004). In addition, brown sandstones have low electrical conductivity (EC) and high percentages of fines (<2mm). Gray sandstone is found at deeper depths underneath brown sandstone and has not been exposed to oxidation and other weathering processes. The pH of gray sandstone ranges from 7.5 to 8.0 (Haering et al., 2004). The weathered, brown sandstone is the preferred topsoil substitute because it is better able to supply nutrients and water to plants (Skousen et al., 2011). Low EC, high percent fines, and lower pH are all correlated with increased tree growth (Daniels and Amos, 1984; Rodrigue and Burger, 2004). Numerous studies across a wide geographic range have shown that brown sandstone promotes superior tree growth over gray sandstone (Angel et al., 2008; Emerson et al., 2009; Sena et al., 2014; Showalter et al., 2009; Wilson-Kokes, 20013a and 2013b). For example, Sena et al. (2009) showed trees on brown sandstone were over 5 times taller than trees on gray sandstone after nine years of growth. Wilson-Kokes et al. (2013b) showed similar findings with brown sandstone having tree volumes of 3853 cm^3 and gray sandstone with 407 cm^3 after eight years of growth. Rodrigue and Burger (2004) found that some reclaimed sites can be just as productive as ummined sites and that poor spoil material have been attributed to reduced survival and growth of trees.

By focusing on the stability of the reclaimed land, as required under SMCRA, excessive compaction became common and caused major impediments to the survival and growth of tree seedlings (Barnhisel, 1988). The compaction of mine soils has been attributed to the most significant SMCRA-related problem for reforestation (Torbert and Burger, 2000). Compaction often occurs during the placement of the topsoil or the topsoil substitute because when dumping and grading occur simultaneous as is common in the Appalachians, the near-surface layers can become heavily compacted (Torbert and Burger, 2000). Creating a smooth surface often results in compaction of soils due to the multiple passes by heavy equipment required to achieve this landscape. Smooth surfaces are not typical of the natural forests found in West Virginia and other Appalachian regions, and do not benefit tree growth or survival (Torbert and Burger, 1992). The use of heavy equipment during reclamation can cause increased bulk density, and reduced porosity, infiltration, water-holding capacity, hydraulic conductivity and root penetration. All of these properties can have adverse effects on the growth of vegetation (Dollhopf and Postle, 1988).

Tree growth is often enhanced by leaving an uncompacted surface because a loose soil surface allows for easier seedling planting, more water infiltration, increased soil water and air capacity, and has less resistance to root growth (Sweigard et al., 2007). Angel et al. (2006) found that tree seedlings growing on uncompacted reclaimed mine soils showed height differences of 154 cm for white oak (*Quercus alba* L.), 204 cm for white ash (*Fraxinus americana* L.), 344 cm for white pine (*Pinus strobus* L.), 185 cm for red oak (*Quercus rubra* L.), 126 cm for black walnut (*Juglans nigra* L.), and 151 cm for tulip-poplar (*Liriodendron tulipifera* L.) over seedlings growing on compacted soils. They concluded that reduced grading (leading to less compaction) is critical to the survival and growth of tree seedlings.

Leaving the surface of a reclaimed mine site with loose soil and a rough surface is preferred over a smooth compacted surface (Torbert and Burger, 1992). Trees will grow in the top 1.2 to 1.8 m of material and growth will be maximized when the material is uncompacted (Conrad et al., 2008). In a study by Fields-Johnson et al. (2010), loose grading on steep slopes resulted in less soil surface loss due to erosion (+10 mm soil surface change) than on intensively graded treatments (-8 mm soil surface change).

The objectives of this study were to:

- Determine the average growth rates of hardwood trees during an 11-year period after reclamation on the following treatments:
    - Brown and gray sandstone;
    - 1.2 and 1.5 m depth of brown sandstone; and;
    - Compacted and uncompacted brown and gray sandstone.
- Determine if growth rates were different for the following treatment comparisons:
    - 1.2 m compacted brown sandstone to 1.2 m uncompacted brown sandstone;
    - 1.5 m compacted brown sandstone to 1.5 m uncompacted brown sandstone;
    - 1.5 m compacted gray sandstone to 1.5 m uncompacted gray sandstone;
    - 1.2 m compacted brown sandstone to 1.5 m compacted brown sandstone
    - 1.2 m uncompacted brown sandstone to 1.5 m uncompacted brown sandstone.
- Determine the soil properties that influenced the growth of hardwood trees during this period.

2.2 Methods

2.2.1 Tree Growth

In 2005, a study was established at the Samples Mine, which is owned by Patriot Coal and operated by Catenary Coal Company. The Samples Mine is located in West Virginia, within the counties of Kanawha, Raleigh, and Boone. Three 2.5-ha demonstration plots were constructed in January 2005 at the Samples Mine, all within Boone County (Figure 2-1). The purpose of these demonstration plots was to evaluate the survival and growth of commercially valuable hardwood tree species planted on two substitute topsoil growth media: unweathered gray sandstone and weathered brown sandstone. Two plots were constructed by placing weathered brown sandstone on the surface, one with 1.5 m and the other with 1.2 m. The third plot was constructed by placing 1.5 m of unweathered gray sandstone on the surface. One half of each plot was considered “uncompacted” when it received only one or two passes of the bulldozer, while the other half received several passes of the bulldozer and was considered “compacted.” A total of six treatments were created (Table 2-1). In March 2005, 11 species of hardwood tree seedlings were planted by a professional planting crew on 2.3 by 2.3 m centers (Table 2-2). All plots were hydroseeded with a mixture of tree compatible herbaceous plants at a rate of 15.4 kg ha^{-1} in the fall of 2005 (Table 2-3).

Tree growth and survival rates have been measured annually since 2005, except no measurements were collected in 2013. Two 2.7-m wide by 195-m long transects were established in an "X" pattern across each of the six treatments (Figure 2-1). Any tree within transects was identified by species, and height to the highest live growth and diameter at 2.5 cm were measured and recorded. Each tree was also assigned a vigor rating of 1 to 5 (Table 2-4). Tree growth was assessed using the formula:

$$\text{Tree volume index } (cm^3) = \text{Height } (cm) \times \text{Stem diameter}^2 \ (cm^2)$$

Table 2-1. Treatments for the reforestation plots established in 2005 at the Catenary Mine in West Virginia.

Treatment	Abbreviation
1.2 m weathered brown sandstone compacted	1.2BC
1.2 m weathered brown sandstone uncompacted	1.2BNC
1.5 m weathered brown sandstone compacted	1.5BC
1.5 m weathered brown sandstone uncompacted	1.5BNC
1.5 m unweathered gray sandstone compacted	GC
1.5 m unweathered gray sandstone uncompacted	GNC

Table 2-2. Number of each tree species planted on reclaimed plots at the Catenary Mine reforestation plots in 2005 in West Virginia.

Species	Number of trees planted	Percent of trees planted
Black cherry (*Prunus serotina* Ehrn.)	465	3
Blacklocust (*Robinia pseudoacacia* L.)	465	3
Chestnut oak (*Quercus prinus* L.)	1250	8
Dogwood (*Cornus alternifolia* L.)	465	3
Eastern redbud (*Cercis canadensis* L.)	465	3
Red oak (*Quercus rubra* L.)	3400	22
Sugar maple (*Acer saccharum* Marsh.)	1500	10
Tulip poplar (*Liriodendron tulipifera* L.)	1250	8
White ash (*Fraxinus americana* L.)	2500	16
White oak (*Quercus alba* L.)	2500	16
White pine (*Pinus strobus* L.)	1250	8
Total	15510	100

Table 2-3. Rates of hydroseeded species at the Catenary Mine reforestation plots in 2005 in West Virginia.

Species	Rate
	--kg ha^{-1}--
Birdsfoot trefoil (*Lotus corniculatus* L.)	11.0
Perennial ryegrass (*Lolium perenne* L.)	2.2
Redtop (*Agrostis gigantea* Roth)	2.2
Total	15.4

Table 2-4. Vigor ratings and descriptions used to assess tree health at the Catenary Mine reforestation plots in West Virginia.

Rating	Modifier	Vigor Category
1	Very poor	>75% leaves discolored; extensive dieback
2	Poor	50-75% discoloration; dieback present
3	Moderate	25-50% leaves discolored; dieback present
4	Good	25-50% leaves discolored; no dieback present
5	Very good	<25% leaves discolored; no dieback present

Figure 2-1. Three plots established in 2005 at the Catenary Mine in West Virginia.

2.2.2 Soils

Soil samples have been collected annually since 2008. Five samples were collected along each “X” for each treatment (resulting in 30 samples each year). Soil samples were collected to a depth of 15 cm. Soil samples were air dried, sieved to pass through a 2-mm screen, and, analyzed for pH, electrical conductivity (EC), and Mehlich 1 extractable nutrients. For pH, a mixture 5 g of soil and 5 ml of deionized water (1:1 ratio) was shaken for 1 hour and analyzed with a Fisher Scientific Accumet pH meter model 915 (Thermo Fisher Scientific Inc., Pittsburgh, PA). After pH was determined, 5 ml of deionized water was added to create 1:2 mixture for EC. EC was then measured with a Mettler Toledo S230 EC meter (Mettler-Toledo International Inc., Columbus, OH) after 1 hour. For extractable nutrients, 40 ml of Mehlich 1 solution (0.025 N H_2SO_4 and 0.05 N HCl) was added to 5 g of soil and shaken for 5 minutes. This solution was then passed through Whatman 42 filter paper. The filtered solution was analyzed for aluminum (Al), calcium (Ca), iron (Fe), magnesium (Mg), manganese (Mn), phosphorus (P), potassium (K), and zinc (Zn) with a ICP-OES (Inductively Coupled Plasma-Optical Emission Spectrometer Perkin-Elmer Corp. DV 2100, Norwalk, CT).

2.2.3 Statistical Analysis

All volume data was transformed to natural log because distributions were not normal determined by Shapiro-Wilk W test. To determine the growth rates of trees over 11 years, regression analysis was completed for each treatment on the volume index of all trees species combined and selected species. Comparisons were made between each combination of two treatments to determine differences in growth rates with Analysis of Covariance (ANCOVA). Specifically, the volume index as an indicator of growth was regressed against age of trees. If significant, interactions between the treatment group and age (covariate) were detected, then separate intercepts and slopes were reported for a particular comparison. Because multiple analyses were made, which increases the likelihood of a type I error, a lower Bonferroni adjustment level was used. Since a total of 25 comparisons were being completed, a significance value of 0.002 (0.05/25) was chosen. Stepwise regression analysis was completed on soils data and average volume data for each year to determine which soil properties were correlated to growth.

2.3 Results and Discussion

2.3.1 Tree Growth

Growth rates were compared between treatments: 1.2BC to 1.2BNC, 1.5BC to 1.5BNC, 1.5BC to 1.2BC, 1.5BNC to 1.2BNC and for GC to GNC. Growth rates were determined for all tree species together, as well as for four individual species: black locust, red oak, white ash, and white oak. These four species were chosen because they had the highest number of trees measured each year and were found in the greatest numbers across treatments. Table 2-5 summarizes the numbers of trees that were measured for each species in each treatment from 2005 to 2015 (except 2008 and 2013). Total numbers of trees measured over all the years varied by treatment and ranged from 566 in GC to 948 in 1.2BNC. Table 2-6 shows the average volume index found on each treatment for each species measured from 2005 to 2015 (except 2008 and 2013) and provides a glimpse of all the data used in the statistical analysis.

Table 2-7 shows aggregate volume index which is the total number of trees multiplied by the average volume index (Table 2-5 multiplied by Table 2-6). Because of the uneven number of tree species present among treatments and years, this table was created to show that black locust, red oak, white ash, and white oak were still considered to be the species with the most growth over all the treatments and years.

Table 2-5. Numbers of trees measured for each treatment from 2007 to 2015 at the Catenary Mine reforestation plots in West Virginia.

		Species[1]												
Treatment	Year	BC	BL	CO	DW	O	RB	RO	SM	TP	WA	WO	WP	Total
		-----Number of Species-----												
1.2BC	2005	3	1	5	3	0	6	14	12	4	24	25	4	**101**
	2006	2	1	5	3	0	4	12	11	1	22	19	8	**88**
	2007	2	1	0	3	0	5	11	9	1	19	18	6	**75**
	2009	1	3	0	1	0	1	12	3	7	20	10	5	**63**
	2010	3	10	0	1	25	2	0	3	4	18	0	5	**71**
	2011	1	27	0	1	0	1	12	3	5	18	16	3	**87**
	2012	0	21	0	1	0	0	8	0	5	15	13	6	**69**
	2014	3	13	0	0	0	1	12	0	0	11	13	1	**54**
	2015	1	16	0	0	0	2	11	0	1	8	30	0	**69**
1.2BNC	2005	2	6	14	7	0	4	24	15	6	19	21	3	**121**
	2006	2	6	14	6	0	4	23	15	6	19	22	10	**127**
	2007	2	6	0	6	0	4	21	14	5	16	30	7	**111**
	2009	1	10	0	3	0	5	17	7	2	11	23	4	**83**
	2010	0	32	0	3	46	4	0	5	3	10	0	6	**109**
	2011	0	36	0	4	0	6	16	0	1	9	25	4	**101**
	2012	0	35	0	2	0	4	14	4	5	6	17	1	**88**
	2014	3	30	0	0	0	2	20	1	7	11	14	3	**91**
	2015	1	43	0	0	0	2	23	2	2	13	31	0	**117**
1.5BC	2005	2	5	9	3	0	4	23	9	11	15	17	9	**107**
	2006	1	5	9	2	0	4	22	9	9	15	16	13	**105**
	2007	1	5	0	2	0	4	16	7	6	12	19	9	**81**
	2009	2	10	0	1	0	2	14	8	5	15	13	9	**79**
	2010	1	8	0	1	27	2	0	8	5	14	0	8	**74**
	2011	2	11	0	1	0	3	14	8	7	19	14	6	**85**

Treatment	Year	BC	BL	CO	DW	O	RB	RO	SM	TP	WA	WO	WP	Total
		Species[1]												
		---Number of Species---												
	2012	0	29	0	3	0	2	14	5	2	13	13	5	**86**
	2014	6	9	0	0	0	1	15	4	8	19	16	4	**82**
	2015	4	20	0	0	0	3	18	7	11	13	22	4	**102**
1.5BNC	2005	3	5	16	6	0	6	23	10	10	15	13	8	**115**
	2006	1	5	14	5	0	6	19	9	8	14	12	15	**108**
	2007	0	5	0	5	0	4	16	5	6	9	16	7	**73**
	2009	2	3	0	3	0	2	18	6	7	15	19	4	**79**
	2010	2	26	0	4	37	2	0	4	8	13	0	4	**100**
	2011	1	36	0	4	0	2	17	6	8	8	17	4	**103**
	2012	1	40	0	2	0	1	10	4	4	8	12	1	**83**
	2014	5	24	0	0	0	1	22	4	4	11	16	0	**87**
	2015	1	17	0	0	0	0	15	3	7	8	21	5	**77**
GC	2005	1	5	1	3	0	8	25	8	11	9	12	6	**89**
	2006	1	5	1	3	0	8	21	8	10	9	11	6	**83**
	2007	1	5	0	3	0	8	19	8	9	9	10	5	**77**
	2009	0	2	0	6	0	0	18	7	6	9	3	7	**58**
	2010	0	1	0	6	22	0	0	5	6	10	0	7	**57**
	2011	0	1	0	7	0	0	17	5	6	14	4	6	**60**
	2012	1	7	0	4	0	1	19	3	10	13	8	4	**70**
	2014	0	8	0	0	0	3	7	1	1	5	9	3	**37**
	2015	1	4	0	0	0	3	13	3	2	3	2	4	**35**
GNC	2005	7	1	6	5	0	2	17	8	12	14	22	5	**99**
	2006	7	1	6	5	0	2	17	8	12	14	22	10	**104**
	2007	7	1	0	3	0	2	16	8	11	11	21	6	**86**
	2009	1	3	0	1	0	2	16	2	4	10	8	7	**54**

Treatment	Year	Species[1] BC	BL	CO	DW	O	RB	RO	SM	TP	WA	WO	WP	Total
		Number of Species												
	2010	1	3	0	1	27	4	0	2	3	6	0	3	**50**
	2011	2	5	0	0	0	3	20	3	7	11	11	4	**66**
	2012	0	1	0	0	0	2	9	1	2	8	6	1	**30**
	2014	2	9	0	0	0	1	12	1	2	4	11	5	**47**
	2015	0	10	0	0	0	2	20	2	4	11	9	6	**64**

[1] BC = black cherry; BL = black locust; CO = chestnut oak; DW = dogwood; O = oak; RB = redbud; RO = red oak; SM = sugar maple; TP = tulip poplar; WA = white ash; WO = white oak; WP = white pine.

Table 2-6. Volume index for all hardwood species for each treatment measured from 2005 to 2015 at the Catenary Mine site in West Virginia.

Treatment	Year	Species[1] BC	BL	CO	DW	O	RB	RO	SM	TP	WA	WO	WP	All
		cm^3												
1.2BC														
	2005	19	16	6	21	NA	16	14	8	8	7	14	2	11
	2006	24	46	11	32	NA	25	23	15	14	13	21	12	18
	2007	100	1864	NA	161	NA	91	139	19	52	123	48	34	109
	2009	813	4082	NA	596	NA	1423	712	145	475	680	673	560	802
	2010	395	349	NA	602	2868	1025	NA	22	548	1178	NA	861	1504
	2011	869	2437	NA	812	NA	1040	1174	113	646	970	2024	2004	1632
	2012	NA	4983	NA	812	NA	NA	2999	NA	687	1009	1167	2121	2550
	2014	484	2968	NA	NA	NA	589	3934	NA	NA	314	3934	5530	2684
	2015	202	8259	NA	NA	NA	452	6020	NA	358	1387	7185	NA	5360
1.2BNC														
	2005	35	18	16	13	NA	20	11	12	27	9	15	3	14

Treatment	Year	BC	BL	CO	DW	O	RB	RO	SM	TP	WA	WO	WP	All
		Species[1]												
		----------------cm^3----------------												
	2006	56	62	17	29	NA	28	20	15	42	20	26	6	23
	2007	541	1552	NA	263	NA	139	148	54	698	227	152	41	255
	2009	2718	9866	NA	1664	NA	959	1132	136	1129	863	975	225	2005
	2010	NA	6522	NA	924	1304	763	NA	578	772	834	NA	447	2667
	2011	NA	6787	NA	1537	NA	1276	2962	NA	527	993	2145	914	3686
	2012	NA	5324	NA	2534	NA	2058	3609	354	3910	3500	3027	762	3913
	2014	3437	11225	NA	NA	NA	2734	6894	3240	4880	4330	7989	86995	10415
	2015	15730	20322	NA	NA	NA	8406	26330	3480	17116	9170	30365	NA	21694
1.5BC														
	2005	18	16	6	14	NA	6	12	11	16	6	16	3	11
	2006	48	54	10	37	NA	8	17	16	15	11	19	7	16
	2007	180	1740	NA	295	NA	116	135	83	109	129	66	155	216
	2009	945	12565	NA	1060	NA	412	597	191	148	633	217	210	1953
	2010	987	22606	NA	1600	966	556	NA	266	466	710	NA	402	3085
	2011	2158	41184	NA	793	NA	1025	3061	217	1429	992	2104	743	6689
	2012	NA	4618	NA	1027	NA	1400	1838	596	154	1487	6427	6820	3556
	2014	6851	2181	NA	NA	NA	5366	8815	3383	3946	4798	13633	2681	7970
	2015	17294	71892	NA	NA	NA	9985	24539	6220	17841	11623	33499	27320	29751
1.5BNC														
	2005	27	16	7	13	NA	25	10	13	18	12	12	4	12
	2006	104	80	14	53	NA	32	17	19	24	25	19	7	23
	2007	NA	2171	NA	248	NA	197	131	60	200	196	122	209	297
	2009	395	17157	NA	1372	NA	388	565	123	1043	563	350	183	1154
	2010	262	3305	NA	1583	910	260	NA	170	1120	578	NA	380	1457
	2011	523	4070	NA	4683	NA	178	1611	228	1445	929	1072	662	2279
	2012	930	7407	NA	8491	NA	358	3181	154	1682	880	5392	4646	5182
	2014	2751	37622	NA	NA	NA	20	7005	619	39409	6471	10171	NA	34004

Treatment	Year	BC	BL	CO	DW	O	RB	RO	SM	TP	WA	WO	WP	All
		Species[1]												
		cm^3												
	2015	3553	25933	NA	NA	NA	NA	12294	10324	3754	9539	19808	34734	18025
GC														
	2005	25	19	12	15	NA	13	10	9	21	4	12	3	12
	2006	40	55	17	21	NA	35	16	16	32	12	27	7	23
	2007	155	130	NA	25	NA	242	38	47	58	52	51	12	71
	2009	NA	24	NA	494	NA		125	40	322	283	117	47	185
	2010	NA	34	NA	496	155	NA	NA	66	333	257	NA	115	213
	2011	NA	47	NA	668	NA	NA	262	80	351	296	5	72	271
	2012	1981	328	NA	1064	NA	1762	397	108	284	711	74	154	449
	2014	NA	683	NA	NA	NA	450	100	105	120	139	131	1048	312
	2015	2835	146	NA	NA	NA	901	335	47	404	97	178	309	430
GNC														
	2005	36	14	7	10	NA	24	13	9	31	10	13	8	16
	2006	65	29	13	15	NA	25	20	15	53	18	26	11	26
	2007	108	58	NA	13	NA	7	27	24	115	26	33	27	45
	2009	120	469	NA	14	NA	7	41	28	646	85	92	42	125
	2010	189	2167	NA	1	85	34	NA	17	969	42	NA	51	249
	2011	161	1901	NA	NA	NA	22	76	20	423	90	140	87	263
	2012	NA	413	NA	NA	NA	376	301	6	908	218	285	114	309
	2014	115	756	NA	NA	NA	14	442	992	180	140	469	532	464
	2015	NA	626	NA	NA	NA	242	416	320	429	182	440	792	494

[1]See footnote in Table 2.5 for abbreviations.

Table 2- 7. Aggregate volume index for all trees species measured between 2005 to 2015 at the Catenary Mine reforestation plots in West Virginia.

		Species[1]												
Treatment	Year	BC	BL	CO	DW	O	RB	RO	SM	TP	WA	WO	WP	All
		------------------------------ cm^3 ------------------------------												
1.2BC														
	2005	56	16	32	63	NA	99	194	100	31	164	345	9	1109
	2006	48	46	56	97	NA	98	280	165	14	279	401	94	1577
	2007	200	1864	NA	482	NA	453	1524	172	52	2340	872	201	8160
	2009	813	12245	NA	596	NA	1423	8546	436	3322	13600	6726	2799	50504
	2010	1186	3492	NA	602	71698	2051	NA	66	2190	21206	NA	4303	106795
	2011	869	65793	NA	812	NA	1040	14094	340	3229	17454	32381	6011	142022
	2012	NA	104647	NA	812	NA	0	23994	NA	3436	15135	15177	12725	175925
	2014	1451	38587	NA	NA	NA	589	47211	NA	NA	3457	51148	5530	144937
	2015	202	132142	NA	NA	NA	903	66215	NA	358	11100	215536	NA	369865
1.2BNC														
	2005	71	105	220	90	NA	82	273	176	165	173	313	9	1677
	2006	112	372	243	175	NA	113	457	230	251	384	569	57	2963
	2007	1082	9314	NA	1577	NA	555	3104	750	3492	3629	4564	287	28354
	2009	2718	98660	NA	4991	NA	4794	19239	951	2258	9489	22418	900	166419
	2010	NA	208698	NA	2772	59970	3054	NA	2892	2315	8340	NA	2682	290722
	2011	NA	244321	NA	6147	NA	7653	47391	NA	527	8935	53634	3658	372266
	2012	NA	186341	NA	5067	NA	8232	50523	1414	19548	21000	51451	762	344338
	2014	10310	336761	NA	NA	NA	5469	137872	3240	34163	47628	111851	260985	947757
	2015	15730	873853	NA	NA	NA	16812	605595	6960	34231	119207	941313	NA	2538161
1.5BC														
	2005	37	79	53	43	NA	22	271	101	178	83	276	31	1175
	2006	48	270	93	75	NA	33	379	142	139	160	303	90	1732
	2007	180	8698	NA	589	NA	462	2161	581	656	1553	1251	1394	17525

Treatment	Year	BC	BL	CO	DW	O	RB	RO	SM	TP	WA	WO	WP	All
							Species[1]							
		------------	------------	------------	------------	------------	------------	cm^3	------------	------------	------------	------------	------------	------------
	2009	1890	125654	NA	1060	NA	824	8359	1526	742	9496	2822	1892	154265
	2010	987	180846	NA	1600	26095	1112	NA	2130	2329	9947	NA	3216	228262
	2011	4316	453020	NA	793	NA	3076	42858	1740	10001	18857	29459	4456	568575
	2012	NA	133928	NA	3082	NA	2799	25737	2980	309	19328	83545	34099	305808
	2014	41105	19629	NA	NA	NA	5366	132223	13531	31571	91167	218134	10724	653546
	2015	69176	1437833	NA	NA	NA	29955	441708	43539	196247	151101	736988	109282	3034645
1.5BNC														
	2005	81	78	106	78	NA	152	234	125	176	175	158	31	1393
	2006	104	399	190	266	NA	190	327	167	189	354	230	109	2525
	2007	NA	10856	NA	1241	NA	786	2094	301	1199	1763	1956	1463	21659
	2009	789	51472	NA	4115	NA	776	10161	737	7303	8447	6654	733	91187
	2010	524	85922	NA	6331	33677	520	NA	681	8963	7517	NA	1519	145653
	2011	523	146528	NA	18732	NA	356	27392	1369	11562	7435	18221	2649	234766
	2012	930	296267	NA	16982	NA	358	31810	618	6726	7041	64704	4646	430083
	2014	13753	902932	NA	NA	NA	20	154107	2478	157634	71180	162734	NA	2958387
	2015	3553	440853	NA	NA	NA	NA	184408	30971	26277	76312	415964	173671	1387934
GC														
	2005	25	93	12	46	NA	106	243	75	232	35	149	15	1032
	2006	40	273	17	64	NA	281	327	131	316	107	292	40	1889
	2007	155	650	NA	74	NA	1933	714	377	523	472	507	58	5463
	2009	NA	49	NA	2967	NA	0	2246	283	1933	2548	352	329	10707
	2010	NA	34	NA	2975	3402	NA	NA	330	2000	2574	NA	803	12119
	2011	NA	47	NA	4675	NA	nA	4451	401	2103	4150	20	435	16282
	2012	1981	2297	NA	4256	NA	1762	7550	324	2840	9239	588	617	31453
	2014	NA	5461	NA	NA	NA	1349	697	105	120	696	1179	3143	11536
	2015	2835	582	NA	NA	NA	2704	4352	140	809	291	356	1234	15049

Treatment	Year	BC	BL	CO	DW	O	RB	RO	SM	TP	WA	WO	WP	All
		Species[1]												
		---- cm^3 ----												
GNC														
	2005	252	14	44	49	NA	49	216	72	372	141	292	40	1541
	2006	454	29	80	74	NA	49	348	117	640	252	565	108	2713
	2007	756	58	NA	39	NA	13	424	189	1262	287	702	161	3891
	2009	120	1406	NA	14	NA	15	661	57	2583	853	735	297	6740
	2010	189	6502	NA	1	2295	134	NA	33	2907	255	NA	154	12469
	2011	321	9507	NA	NA	NA	66	1528	59	2960	995	1544	348	17327
	2012	NA	413	NA	NA	NA	752	2707	6	1815	1744	1711	114	9262
	2014	231	6804	NA	NA	NA	14	5307	992	360	561	5156	2659	21802
	2015	NA	6260	NA	NA	NA	485	8315	640	1715	2005	3957	4751	31611

[1]See footnote for Table 2.5 for abbreviations.

Figure 2-2 shows the standard error bars for the average growth over 11 years for each treatment. Figure 2-2 also shows that the distribution of species varied by each treatment. During the initial planting in 2005, the strategy of the planters was to randomly distribute the trees and our data support this strategy with each treatment having a different number of trees. In addition, Figure 2-2 shows that the average tree volume on each treatment increased, with some decreases, since 2005 and that the amount of growth varied among treatments. Reasons for growth decreases in some years include sampling errors (not all the same trees were measured each year), or large trees may have died. The scale for tree volume on the y axis is not the same for each treatment. Growth rates were not the same over all ages and the comparisons were done for an average growth rate over all the years. The results of the ANCOVA analysis are shown in Table 2-6.

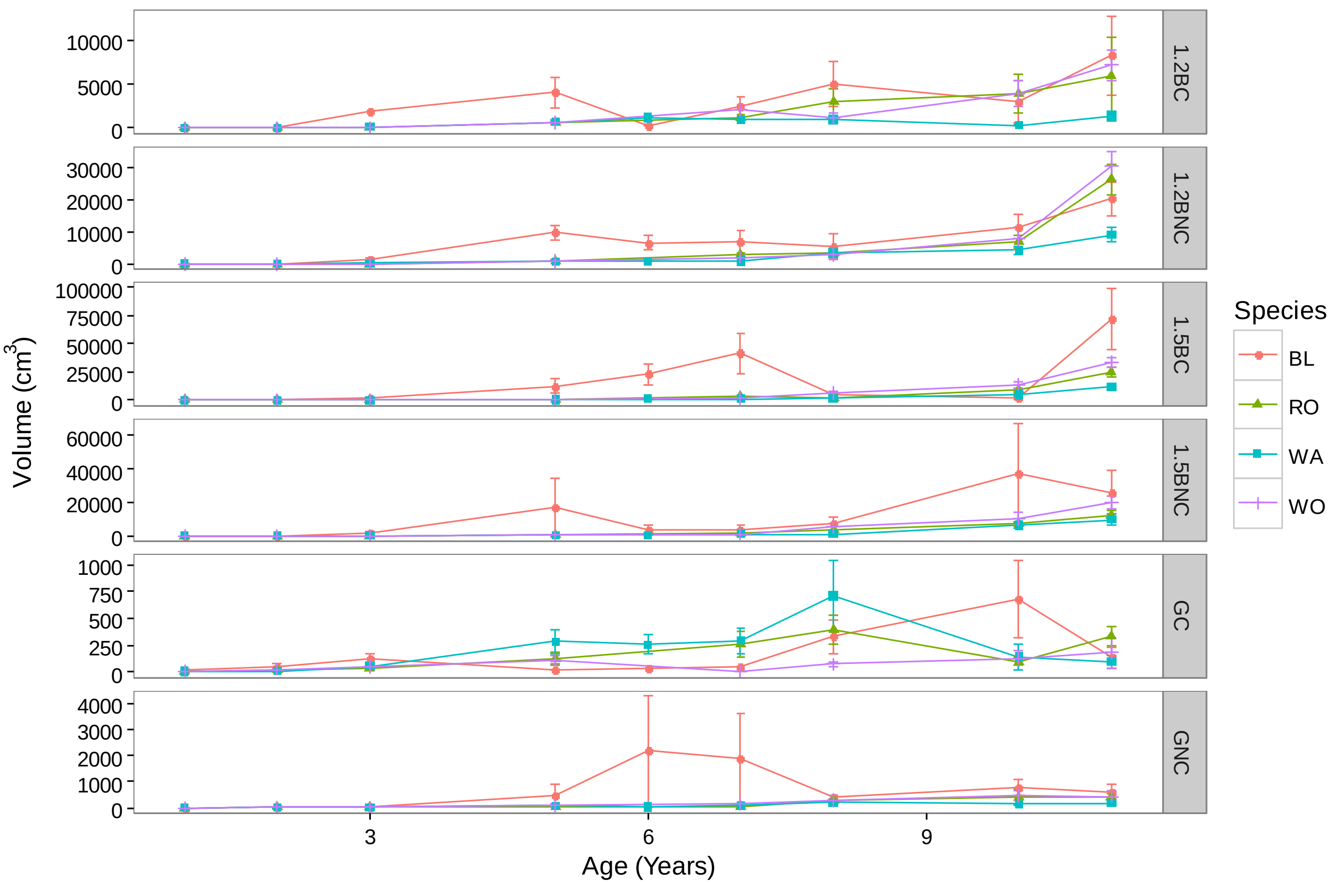

Figure 2-2. Average black locust, red oak, white ash, and, white oak growth over eleven years at the Catenary mine reforestation plots by treatment (with error bars). Note different scales between treatments.

Table 2-8. Statistical results from ANCOVA analysis for yearly volume index growth for all species combined, black locust, red oak, white ash, and white oak at the Catenary mine reforestation plots in West Virginia.

Species/Comparisons	Intercept	Slope	P	R^2
All				
1.2BC	2.15	0.49	**<0.0001**	0.60
1.2BNC	2.16	0.62		
BL				
1.2BC	3.98	0.24	0.1935	0.15
1.2BNC	3.38	0.41		
RO				
1.2BC	2.66	0.48	**<0.0001**	0.78
1.2BNC	2.05	0.70		
WA				
1.2BC	2.24	0.50	0.0074	0.65
1.2BNC	2.09	0.64		
WO				
1.2BC	1.76	0.56	**0.0008**	0.73
1.2BNC	1.88	0.71		
All				
1.5BC	1.64	0.70	**<0.0001**	0.66
1.5BNC	2.03	0.58		
BL				
1.5BC	4.10	0.40	0.9389	0.20
1.5BNC	3.22	0.42		
RO				
1.5BC	1.74	0.72	0.1626	0.82
1.5BNC	1.77	0.67		
WA				
1.5BC	1.50	0.70	0.0078	0.75
1.5BNC	2.23	0.56		
WO				
1.5BC	1.24	0.80	**0.0019**	0.79
1.5BNC	1.85	0.64		
All				
1.2BC	2.15	0.50	**<0.0001**	0.65
1.5BC	1.65	0.70		
BL				

Species/Comparisons		Intercept	Slope	P	R^2
	1.2BC	3.98	0.24	0.1951	0.19
	1.5BC	4.10	0.43		
RO					
	1.2BC	2.66	0.48	**<0.0001**	0.77
	1.5BC	1.74	0.72		
WA					
	1.2BC	2.24	0.50	**<0.0001**	0.70
	1.5BC	1.50	0.70		
WO					
	1.2BC	1.76	0.56	**<0.0001**	0.76
	1.5BC	1.24	0.80		
All					
	1.2BNC	2.16	0.62	0.0924	0.61
	1.5BNC	2.04	0.58		
BL					
	1.2BNC	3.38	0.41	0.8650	0.18
	1.5BNC	3.22	0.42		
RO					
	1.2BNC	2.05	0.70	0.3147	0.82
	1.5BNC	1.77	0.67		
WA					
	1.2BNC	2.09	0.64	0.1953	0.57
	1.5BNC	2.23	0.57		
WO					
	1.2BNC	1.88	0.71	0.1546	0.75
	1.5BNC	1.86	0.65		
All					
	GC	2.37	0.25	0.2392	0.17
	GNC	2.29	0.21		
BL					
	GC	3.16	0.17	0.5939	0.11
	GNC	4.15	0.17		
RO					
	GC	2.13	0.29	0.1777	0.25
	GNC	1.95	0.21		
WA					
	GC	1.77	0.39	0.0427	0.33
	GNC	2.21	0.24		
WO					

Species/Comparisons	Intercept	Slope	P	R^2
GC	2.49	0.10	0.7475	0.05
GNC	2.49	0.13		

[1] Bold indicates significant difference of growth rates.

Growth rates for all trees combined were found to be significantly different for all comparisons, except for GC to GNC and 1.2BNC to 1.5BNC (Table 2-7). 1.2BNC had a higher growth rate (slope of 0.62 cm^3/year) than 1.2BC with a slope of 0.49 cm^3/year (Figure 2-3). For the 1.5 plot, growth was significantly higher in the compacted (1.5BC) with a slope of 0.70 cm^3/year over the non-compacted plot (1.5BNC) with a slope of 0.58 cm^3/year. These results were unexpected as compaction usually hinders the growth of trees (Angel et al., 2006; Conrad et al., 2008; Emerson et al., 2009; Torbert and Burger, 1992; Wilson-Kokes et al., 2013b). One reason for this discrepancy is that a portion of the 1.5BNC plot is inundated with water for winter and spring months during the year and the trees growing in that area have not grown well. This is likely the reason why the tree growth rates are lower here than in the compacted side. Depth appears to have a greater effect on tree growth when the soil is compacted than when uncompacted. Growth rates were found to be significantly different when comparing 1.2BC to 1.5BC (slopes of 0.70 vs 0.50 cm^3/year) but not when comparing 1.2BNC to 1.5BNC (slopes of 0.62 and 0.58 cm^3/year). However, since the growth on the 1.5BNC was found to be low (due to saturated conditions) it is possible this is the reason no significant difference was found.

When comparing growth rates for black locust only, no significant differences were found for any comparisons (Table 2-7). Black locust is known to rapidly invade and colonize disturbed sites, especially reclaimed surface mines, regardless of the reclamation practices (Huntley, 1990). A study by Shuster and Hutnik (1987) found that black locust had naturally colonized 58% of plots on reclaimed sites over 30 years old. Black locust grows well on mine sites because it is tolerant of the harsh conditions of mine soils and can grow across a broad range of pH conditions and can tolerate coarse-textured and compacted soils. It belongs to the Fabaceae family and has nitrogen-fixing capabilities due to Rhizobium bacteria forming nodules. It also is a prolific seed producer early in its growth cycle, which are spread rapidly by birds and other vectors. Black locust has rapid juvenile growth and is able to readily produce sprouts from roots. Sprouts of black locust can grow more rapidly than seedlings (Huntley, 1990). As a result of its prolific sprouting and seed recruitment, many black locust seedlings were present and measured in each transect. Table 2-5 shows that the number of black locust present in most of the treatments increased from 2005 to 2015. The increase of the total number of black locust trees measured is due to sprouting and new seedling growth from seeds and as a result, the growth for black locust has a much larger standard error than for other species (Figure 2-2).

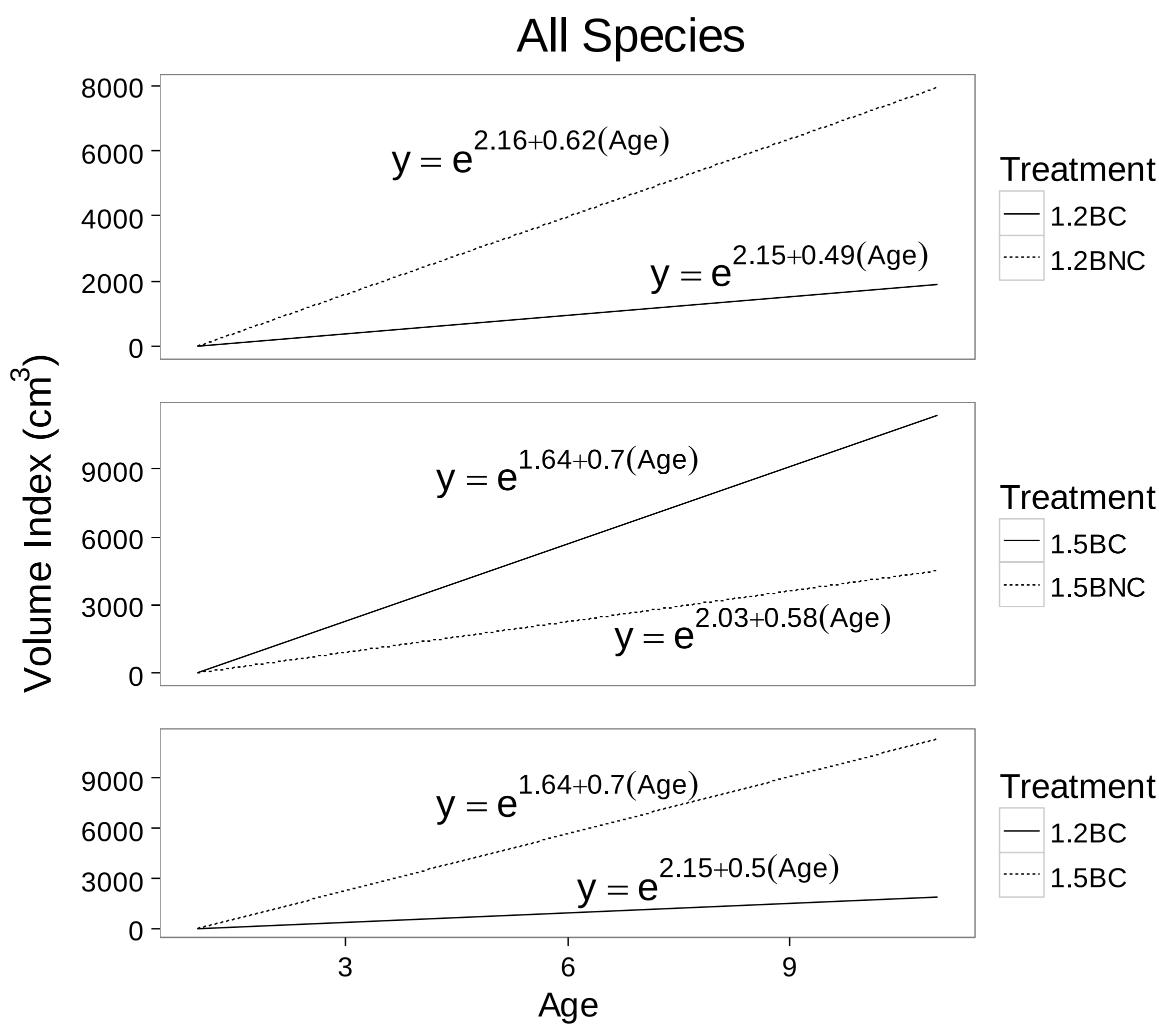

Figure 2-3. Treatment comparisons showing significant differences in average growth rates over 11 years for all tree species combined at the Catenary Mine reforestation plots in West Virginia.

Significant differences were found for the growth rates of red oak when comparing 1.2BNC to 1.2BC and 1.2BC to 1.5BC (Table 2-7; Figure 2-4). With a slope of 0.70 cm^3/year, 1.2BNC had a higher growth rate than 1.2BC with a slope of 0.48 cm^3/year. Greater depth of sandstone resulted in 1.5BC having a higher growth rate (slope of 0.72 cm^3/year) than 1.2BC (slope of 0.48 cm^3/year). Red oak is able to grow on a variety of soils and topography (Sander, 1990). As with the other comparisons, the significantly higher growth on the compacted side of the 1.5 m plot was unexpected but most likely a result of the saturated conditions on part of the plot.

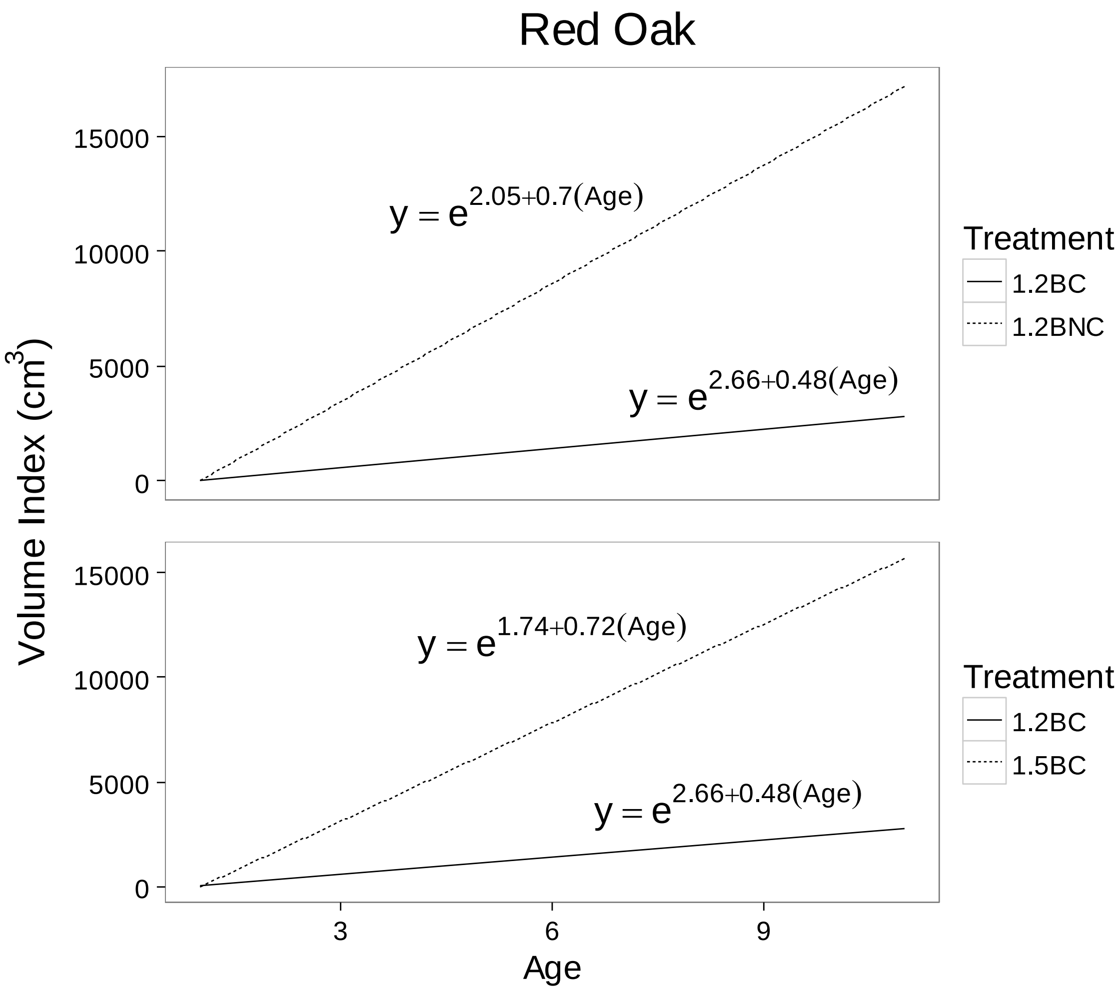

Figure 2-4. Treatment comparisons showing significant differences in average growth rates over 11 years for red oak at the Catenary Mine reforestation plots in West Virginia.

Growth rates for white ash were significantly different only when comparing 1.2BC to 1.5BC and were higher for 1.5BC with a slope of 0.70 cm^3/year (Figure 2-5). Figure 2-2 shows that the standard error of white ash trees was highest in 2015 at age 11 (except for GC and GNC). In 2015, most of the white ash were rated as having a vigor of 3, which indicated that 25 to 50% of the leaves were showing dieback (See Appendix A for vigor data). The soil fertility and soil moisture requirements of white ash are high and it is possible that mine soils are not able to provide adequate requirements. In 2013, white ash was found to have the second lowest volume of all the species (Wilson-Kokes, 2013b). Other possible causes of white ash dieback include deer browsing or emerald ash borer (Schlesinger, 1990). Emerald ash borer has been found in sapling stage ash trees (Aubin et al., 2015). White ash is sometimes considered to be a riparian species that grows well early on when used in reclamation; however, it has also been found that white ash can be outgrown by more upland species as they become more established (Burger and Fannon, 2009). Many of the trees planted on the site are considered upland species.

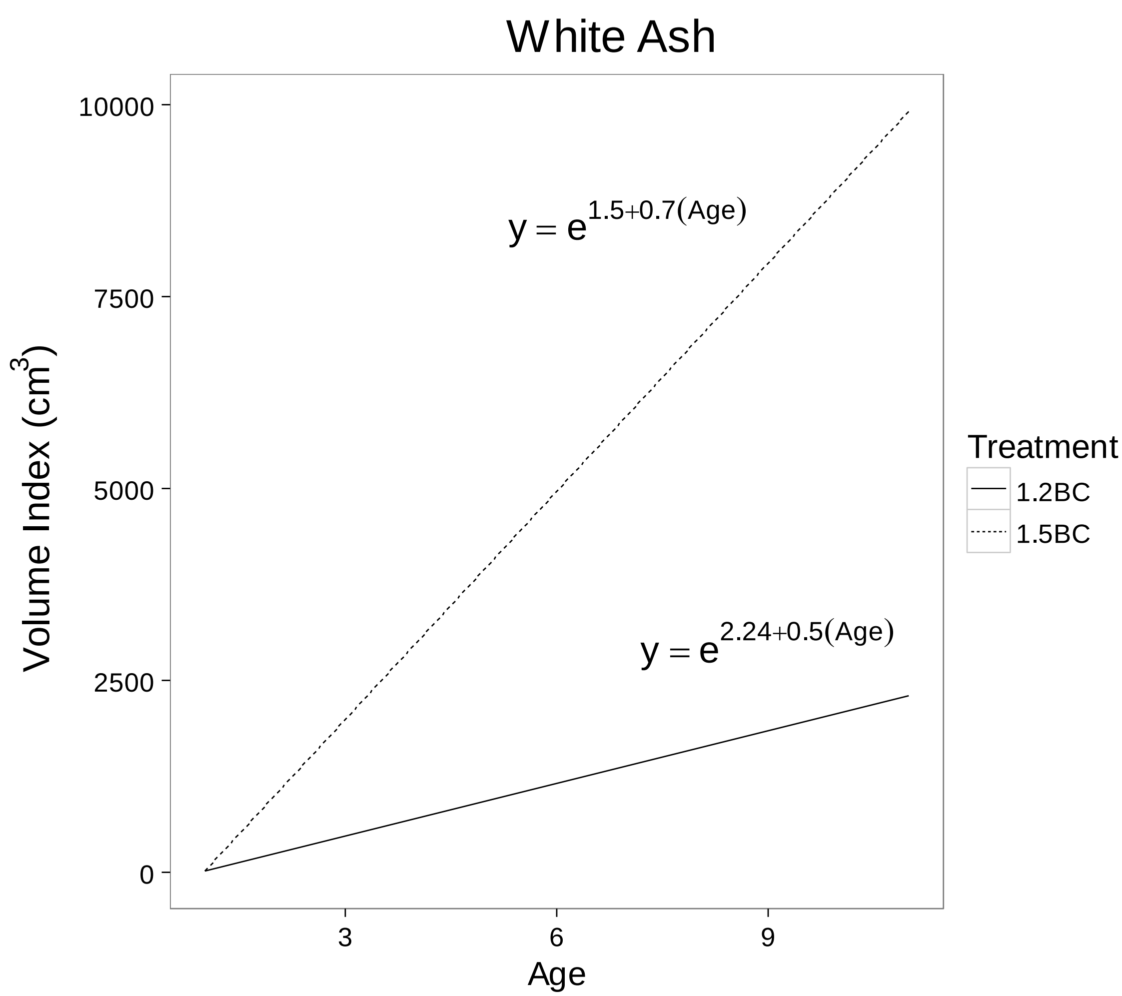

Figure 2-5. Treatment comparisons showing significant differences in average growth rates over 11 years for all white ash at the Catenary Mine reforestation plots in West Virginia

For white oak, growth rates were found to be significantly different when comparing 1.2BC to 1.2BNC, 1.5BC to 1.5BNC and1.2BC to 1.5BC (Figure 2-6). Growth rates were higher in the uncompacted side in the 1.2 plot (0.71 cm^3/year) but higher in the compacted side of the 1.5 plot

(0.80 cm^3/year). This was an unexpected result since white oaks prefer loose soils (Rogers, 1990). Showalter et al. (2007) found that the growth of white oak seedlings in mine soils is most successful on northeast facing slopes, with slightly acidic pH, sandy loam texture, high nutrient levels, and high microbial populations. As with the other species, the higher growth rate on the compacted side of the 1.5 m plot is contrary to what other studies have shown.

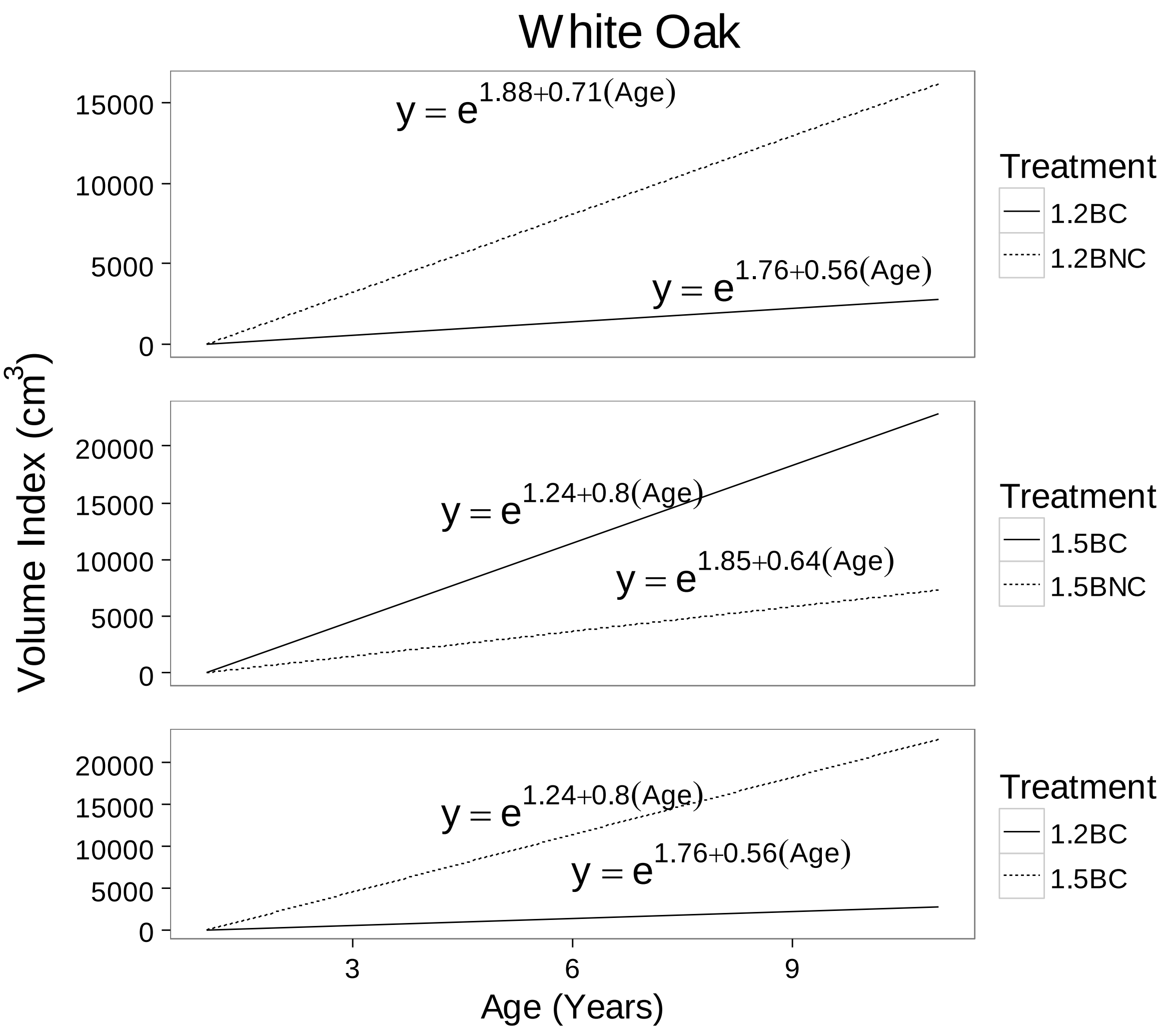

Figure 2-6. Treatment comparisons showing significant differences in average growth rates over 11 years for white oak at the Catenary Mine reforestation plots in West Virginia.

2.3.2 Soils

Table 2-8 shows the average of all soils data from 2005, 2009-2012, 2014, and 2015. Soils data were not available for 2008 and 2013. The pH for all the brown sandstone treatments was within excepted values and ranged from 4.6 on 1.2BNC in 2009 to 6.6 on 1.5BC in 2015. Both of the gray sandstone plots also had pH within expected values and pH ranged from 6.5 on GNC in 2015 after 11 years of weathering to 8.3 on GNC in the early years (2005). EC values for all treatments for all years were very low and ranged from 0.01 to 0.53. Between 2005 and 2015, percent fines of all the treatments increased, with the highest increases seen in 1.2BC and 1.2BNC (increase of 19%) and the lowest increase seen in the GC plot (increase of 2%). Much variance was found between years for many of the extractable nutrients. For example, on 1.2BC Mn ranged from 26 mg/kg in 2009 to 616 mg/kg in 2005. Variance was also seen on the gray sandstone treatments with Mn ranging from 51 mg/kg in 2009 to 322 in 2010 in GNC plot. Reasons for the variance in soil extractable nutrients could be due to a large variance in mine soils, or differences in laboratory procedures between different samplers.

The results of the stepwise regression are shown in Table 2-9. Mn and Zn were not included in the stepwise regression due to missing data from 2014. For all species, black locust, red oak, and white oak, three soil properties consistently were chosen as the ones that were most responsible for tree volume: percent fines, Mg and Ca. Percent fines, Mg, Ca, and additional property Fe were selected for white ash. Figures 2-7 to 2-9 show the volume growth for all tree species with the three selected properties. Our results overlap somewhat with other studies which found pH, Ca, P, cation exchange capacity, base saturation, EC, and coarse fragment content to be correlated to tree growth (Burger and Fannon, 2009; Rodrigue and Burger, 2001). So the properties connected to tree growth which were common among studies are Ca and percent fines. The trend between volume growth and soil properties are difficult to discern in Figures 2-7 to 2-9. This is due to the high variability in soils properties, as well as growth between the years. The purpose of showing the stepwise regression analysis was to show that even though there is high variability, the results of the analysis were still consistent with other studies.

Table 2-9. Average soil properties values for all treatment for 2005, 2009 to 204, and 2015 at the Catenary Mine reforestation plots in West Virginia.

Treatment	Year	pH	EC	Fines	Al	Fe	Mn	P	Zn	Ca	K	Mg
			-d Sm^{-1}-	-%-	----------------------	mg kg^{-1}	----------------------			-----------cmol$_c$ kg^{-1}----------		
1.2BC	2005	4.7	0.53	49	708	430	617	22	13.0	2.3	0.2	9.6
	2009	4.7	0.13	56	79	33	27	35	1.5	0.9	0.5	0.9
	2010	4.8	0.15	48	554	254	176	42	14.7	5.3	0.7	5.0
	2011	5.5	0.52	52	348	161	159	46	8.7	14.0	0.4	4.6
	2012	5.2	0.04	76	356	149	138	44	9.1	4.7	0.4	4.0
	2014	4.7	0.01	65	472	177	NA	24	NA	4.5	0.5	3.4
	2015	5.1	0.08	68	93	37	33	15	2.1	0.9	0.2	0.6
1.2BNC	2005	5.2	0.28	48	626	873	356	23	18.5	2.3	0.2	7.7
	2009	4.6	0.17	55	81	33	28	27	2.0	0.9	0.5	0.9
	2010	5.1	0.09	45	485	226	187	53	12.4	6.6	0.6	6.2
	2011	6.5	0.48	44	219	158	176	104	10.4	8.2	0.5	5.2
	2012	5.4	0.04	69	289	134	135	39	6.7	4.9	0.5	4.6
	2014	5.4	0.01	59	405	134	NA	37	NA	7.7	0.8	4.9
	2015	5.5	0.04	67	91	43	39	10	1.7	0.9	0.2	0.6
1.5BC	2005	6.0	0.39	50	452	322	376	36	12.5	2.8	0.2	10.3
	2009	6.1	0.09	60	43	21	28	37	2.3	1.2	0.9	1.2
	2010	6.1	0.10	38	463	224	211	85	12.1	11.3	0.8	9.7
	2011	5.5	0.35	58	335	135	104	38	5.6	4.5	0.4	3.5
	2012	5.6	0.05	69	256	137	154	71	8.2	7.2	0.5	4.9
	2014	6.0	0.00	58	339	123	NA	65	NA	8.9	0.6	5.9
	2015	6.6	0.04	67	59	46	45	22	1.8	2.0	0.2	1.1
1.5BNC	2005	4.7	0.43	53	593	357	409	20	12.3	1.8	0.2	6.8
	2009	5.8	0.16	47	49	23	26	38	1.5	1.2	0.8	1.2

Treatment	Year	pH	EC	Fines	Al	Fe	Mn	P	Zn	Ca	K	Mg
			-d Sm^{-1}-	-%-	-----------------------	mg kg^{-1}	-----------------------			-----------$cmol_c$	kg^{-1}	----------
	2010	6.4	0.14	50	324	251	191	129	9.8	13.0	0.6	10.3
	2011	5.5	0.50	48	408	186	179	44	7.3	4.6	0.3	4.3
	2012	5.7	0.03	69	229	149	132	56	7.6	6.8	0.4	5.3
	2014	5.4	0.01	58	506	182	NA	39	NA	8.5	0.7	4.7
	2015	6.4	0.04	65	65	58	40	17	1.3	1.7	0.1	1.0
GC	2005	7.6	0.21	40	302	617	257	59	21.9	3.2	0.2	7.8
	2009	7.8	0.10	37	16	41	34	41	4.1	1.2	0.9	1.2
	2010	7.3	0.10	34	163	492	257	272	14.6	11.7	0.6	7.8
	2011	7.9	0.41	38	116	312	199	190	14.9	8.0	0.3	6.0
	2012	7.9	0.04	41	76	203	192	176	15.6	8.4	0.1	6.7
	2014	7.1	0.01	45	153	147	NA	168	NA	8.1	0.5	5.8
	2015	7.7	0.06	42	28	41	39	55	4.6	1.9	0.1	1.1
GNC	2005	8.3	0.20	36	202	1054	115	63	28.3	2.8	0.2	7.6
	2009	8.2	0.10	37	18	88	51	21	4.0	1.4	1.4	1.4
	2010	7.6	0.11	25	164	722	322	293	20.7	18.1	0.6	8.9
	2011	7.9	0.46	36	104	288	177	198	17.3	9.5	0.3	5.1
	2012	8.0	0.06	36	81	243	186	191	16.5	8.9	0.0	6.1
	2014	6.5	0.01	39	151	151	NA	191	NA	11.0	0.4	5.2
	2015	7.9	0.07	61	27	81	52	39	2.1	2.4	0.1	1.3

Table 2-10. Statistical results from stepwise regression of soil properties and average volume index over 11 years for all species combined, black locust, red oak, white ash, and white oak at the Catenary Mine reforestation plots in West Virginia.

Species	Variable	P	R^2
All	Fines	<0.0001	
	Mg	<0.0001	0.72
	Ca	<0.0001	
BL	Fines	0.0001	
	Mg	<0.0001	0.60
	Ca	<0.0001	
RO	Fines	<0.0001	
	Mg	<0.0001	0.79
	Ca	<0.0001	
WA	Fines	0.0003	
	Fe	0.0459	0.70
	Mg	0.0047	
	Ca	<0.0001	
WO	Fines	<0.0001	
	Mg	<0.0001	0.77
	Ca	<0.0001	

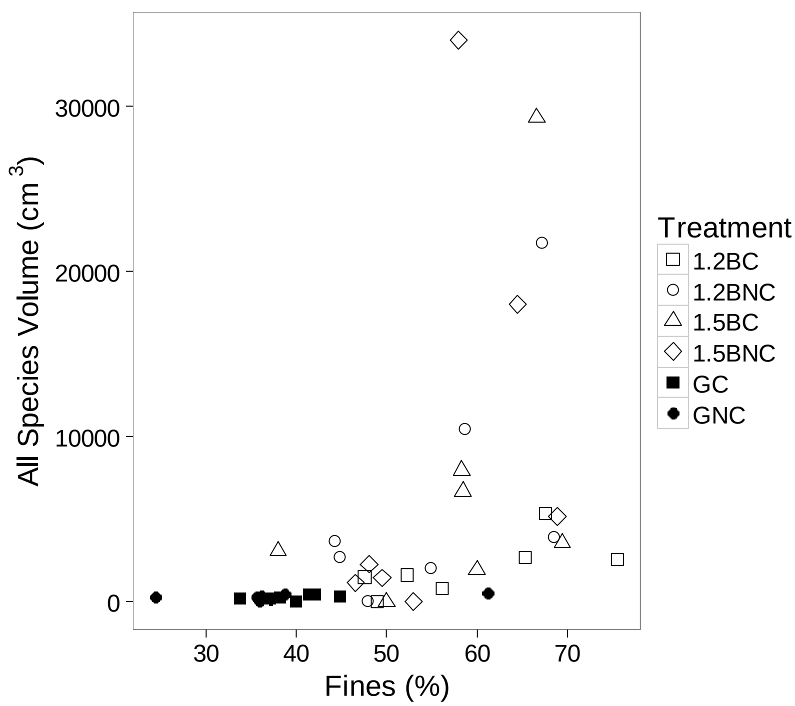

Figure 2-7. Relationship of average volume index of all tree species combined over 11 years to percent fines at the Catenary Mine reforestation plots in West Virginia.

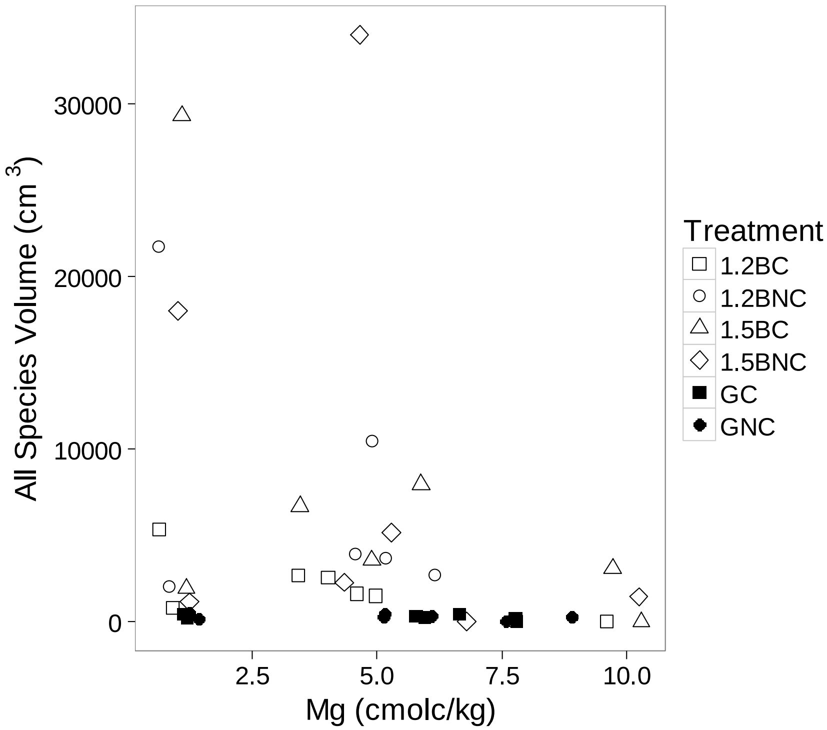

Figure 2-8. Relationship of average volume for all tree species combined over 11 years to magnesium at the Catenary Mine reforestation plots in West Virginia.

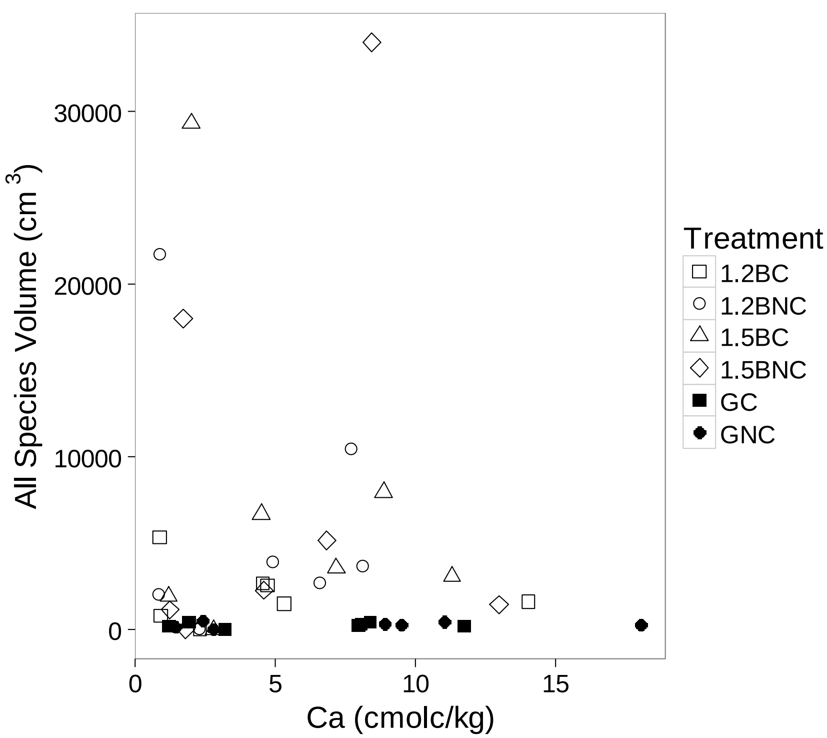

Figure 2-9. Relationship of average volume index of all tree species combined over 11 years to calcium at the Catenary Mine reforestation plots in West Virginia.

2.4 Conclusion

Brown sandstone was a better medium for the growth of trees than gray sandstone. In addition to using the proper growing medium, site preparation techniques were important to improved growth and survival of trees. Compaction hinders the growth of trees and it is important that sites being reclaimed with trees are not compacted during soil placement. While compaction usually negatively affects the growth rates of trees, other factors also must be considered. When comparing the effects of compaction on the 1.5-m brown plot, the growth rates were higher on the compacted site. On this plot, poor drainage conditions on a large portion of the plot contributed to poor overall growth of trees on the non-compacted side. But on 1.2 brown, non-compacted plots showed better tree growth. Growth on gray sandstone was poor even when non-compacted and is not recommended as a suitable topsoil substitute. Selection of tree species is also important as certain species are more suited to mine soil conditions than others. Black locust showed better growth than any other planted trees on these sites, and increased its density due to prolific seed recruitment and root sprouting. Red oak grows well on a variety of soils and is considered a good reclamation species. White oak grows well on loose, acidic soils and is therefore well suited to brown sandstone. Over the eleven years of this project, soil elemental concentrations varied widely across and within treatments. Even with the high variance, percent fines, Ca, and Mg were correlated to the growth of the trees, though the correlation was low. Other studies have found that pH and EC are also important for good tree growth on mine soils. Brown sandstone was found to have appropriate levels of these soil properties important for tree growth and is therefore considered a suitable topsoil substitute, and superior to gray sandstone. Successful coal mine reclamation in the Appalachians should be supported by the use of a proper growing medium, such as brown sandstone, and leaving the surface uncompacted.

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3.0 Growth Rates of Hardwood Trees Nine Years After Reclamation at the Birch River Mine Site

3.1 Literature Review

Surface mulch can be applied to improve plant growth conditions (Norland, 2000). Tree growth is improved because mulches help to control erosion, supply nutrients to seedlings, reduce evaporation at the soil surface, increase water holding capacity, increase organic matter, and control soil temperatures (Conrad et al., 2008; Norland, 2000). Mulch also improves soil structure and reduces compaction (Conrad et al., 2008). A study by Showalter et al. (2010) found that tree growth was improved in unweathered shale when a topsoil amendment was added. Although tree growth was not improved in unweathered sandstone, the addition of a topsoil amendment was still found to lower pH and improve soil fertility, which are beneficial to tree growth. Many studies have also shown that tree growth on both brown and gray sandstone can be improved with amendments (Angel et al., 2006; Thomas and Skousen, 2011; Wilson-Kokes et al., 2013a). For example, Angel et al. (2006) found that both bark mulch and straw amendments increased the height of white oak, white ash, northern red oak, black walnut, and yellow poplar on compacted plots. Four years after reclamation, the volume of trees growing on brown sandstone was increased from 571 cm^3 to 973 cm^3 when bark mulch was added, while on gray sandstone the volume of trees was increased from 134 cm^3 to 539 cm^3 with the addition of bark mulch (Thomas and Skousen. 2011). Wilson-Kokes et al. (2013a) found similar results after seven years with the volume of hardwood trees increasing from 4194 cm^3 to 6187cm^3 when bark mulch was added. Bark mulch can add nutrients and improve water holding capacity and also increase the foliar concentration of potassium and magnesium (Wilson-Kokes and Skousen, 2014).

Soil organic matter was increased one year after treatment when sawdust and sewage sludge were added to mine soils consisting of sandstone and siltstone (Bendfeldt et al., 2001). In this study five years later, SOM was increased in the control and sewage sludge plots due to inputs from root and litter cycling and decomposition of soil organisms. By 16 years, SOM levels had equilibrated between 8 to 10 Mg ha^{-1} in treated and control plots. It was concluded that organic inputs from vegetation in the control plots were enough to raise the SOM to levels similar to the amended plots. This shows the importance of vegetation cover early in the reclamation process.

Organic inputs from vegetation were also thought to play an important role in the formation of aggregates in the soil.

Herbaceous cover and trees compete for space, light, water, and nutrients. Competition exists among plants occupying adjacent or over-lapping spaces. Positive effects between plants can also occur when one plant alters the physical environment in a way that benefits a neighboring plant. For example, shading the soil surface can reduce temperatures. Root growth and decay affects soil density, infiltration rates, and water-holding capacity by increasing SOM. On coarse textured substrates with a low water-holding capacity, like mine soils, competition effects between herbaceous cover and tree seedlings can be strong. Ground cover can have a positive influence on mine soil hydrologic properties and planting herbaceous cover on a new reclaimed site can modify the environment and have positive influence on the growth of seedlings. Short term negative effects, such as water or nutrient deficiencies, can often be tolerated by tree seedlings, while continuous competition over a long period may more seriously impact the growth and survival of trees. The environment around tree seedlings is modified by herbaceous plants because of the increase in shading and organic matter (Franklin et al., 2012). Herbaceous cover also increases infiltration rates (Loch, 2000). Survival of planted trees was reduced 12 to 33% on a reclaimed coal mine in West Virginia when compared to an unseeded treatment (Delong and Skousen, 2010).

High herbaceous cover can also present a challenge to the growth of trees and result in a failure of forest regeneration (George and Bazzaz, 2014) so the FRA recommends using a tree compatible ground cover to limit competition with seedlings (Burger et al., 2009). A tree compatible ground cover uses less competitive species, requires lower seeding rates and less nitrogen fertilizer, and produces a less dense cover. Tree seedlings will grow better with compatible cover because they will receive more light, water, and nutrients (Burger et al., 2009). Tree compatible herbaceous species are sown at low rates, are short in stature, and have a low water and nutrient demand. These characteristics allow them to not compete aggressively with planted tree seedlings (Franklin et al., 2012). An example of a tree compatible species is annual rye grass (*Lolium perenne* L.) because it was found to not reduce survival of tree seedlings or increase soil erosion (Fields-Johnson et al., 2010).

The objectives of this study were to:

- Determine the average growth rates of hardwood trees during an 9-year period after reclamation on the following treatments:
    - Brown and gray sandstone;
    - Brown and gray sandstone with mulch;
    - Brown and gray sandstone with hydroseed; and;
    - Brown and gray sandstone with mulch and hyroseed.
- Determine if growth rates were different for the following treatment comparisons:
    - 1.2 m compacted brown sandstone to 1.2 m uncompacted brown sandstone;
    - 1.5 m compacted brown sandstone to 1.5 m uncompacted brown sandstone;
    - 1.5 m compacted gray sandstone to 1.5 m uncompacted gray sandstone;
    - 1.2 m compacted brown sandstone to 1.5 m compacted brown sandstone
    - 1.2 m uncompacted brown sandstone to 1.5 m uncompacted brown sandstone.
- Evaluate the soil properties that influenced the growth of hardwood trees during this period.

3.2 Methods

3.2.1 Tree Growth

In November 2006, a 2.5-ha experimental plot was established at the Birch River mine to determine the effects of soil amendments on tree growth and survival on brown and gray sandstone. The mine is owned by Arch Coal and located in Webster County, WV. Half the plot was constructed with approximately 1.5 m of brown sandstone and the other half was constructed with approximately 1.5 m of gray sandstone. To limit compaction on the study plot, only one pass of the bull dozer was used to create a roughly-graded surface throughout the plot. In the spring of 2007, 15 cm of bark mulch was applied to the center of the plot over both brown and gray sandstone. The bark mulch contains limestone, which was added as an aggregate at the sawmill. A professional planting crew then planted 12 tree species at 2.5 m centers for a stocking rate of about 1,450 trees per ha (Table 3-1). In the fall of 2007, each end of the plot (which included brown and gray areas with and without mulch) was hydroseeded with a mix of tree compatible herbaceous vegetation at a rate of 35.7 kg ha^{-1} (Table 3-2) and fertilized with 10-20-10 NPK at a rate of 336 kg ha^{-1}. A total of eight treatments were created (Table 3-3) and are shown in Figure 3-1.

Table 3-1. Number of each tree species planted on reforestation plots at the Birch River Mine in 2007 in Webster County, West Virginia.

Species	Number of trees planted	Percent of trees planted
Black cherry (*Prunus serotina* L.)	425	11
Black locust (*Robinia pseudocacia* L.)	400	10
Dogwood (*Cornus alternifolia* L.)	175	4
Eastern redbud (*Cercis canadensis* L.)	175	4
Eastern white pine (*Pinus strobus* L.)	200	5
Northern red oak (*Quercus rubra* L.)	425	11
Pitch X loblolly pine (*Pinus X rigitaeda)*	400	10
Sugar maple (*Acer saccharum* Marsh.)	425	11
Sycamore *(Platanus occidentalis* L.)	225	6
Tulip poplar (*Liriodendron tulipifera* L.)	300	8
White ash (*Fraxinus americana* L.)	425	11
White oak (*Quercus alba* L.)	425	11
Total	4000	100

Table 3-2. Rates of hydroseeded species at the Birch River Mine reforestation plots in 2007 in Webster County, West Virginia.

Species	Rate
	-----kg ha^{-1}----
Birdsfoot trefoil (*Lotus corniculatus* L.)	11.2
Kobe lespedeza (*Kummerowia striata* Maxim.)	5.6
Ladino clover (*Trifolium repens* L.)	3.3
Orchard grass (*Dactylis glomerata* L.)	5.6
Perennial ryegrass (*Lolium perenne* L.)	5.6
Redtop (*Agrostis gigantea* Roth)	2.2
Weeping lovegrass (*Eragrostis curvula* Schra.)	2.2
Total	35.7

Tree survival and growth measurements have been collected annually since 2007, except no data was collected in 2013. Eleven 2.7-m wide transects, each spanning the width of the experimental plot, were used to determine tree volume index and survival. All trees within transects were identified by species, and height to the highest live growth and diameter at 2.5 cm were measured and recorded. Beginning in 2012, tree diameters were also collected at 10 cm. Each tree was also assigned a vigor rating of 1 to 5 (Table 4). Tree growth was assessed using this formula:

$$\text{Tree volume index (cm}^3\text{)} = \text{Height (cm) x Stem diameter}^2 \text{ (cm}^2\text{)}$$

Table 3-3. Treatments established in 2006 and 2007 at the Birch River Mine reforestation plots in Webster County, West Virginia.

Treatment	Abbreviation
Brown	B
Brown with hydroseeding	BH
Brown with mulch	BM
Brown with mulch and hydroseeding	BMH
Gray	G
Gray with hydroseeding	GH
Gray with mulch	GM
Gray with mulch and hydroseeding	GMH

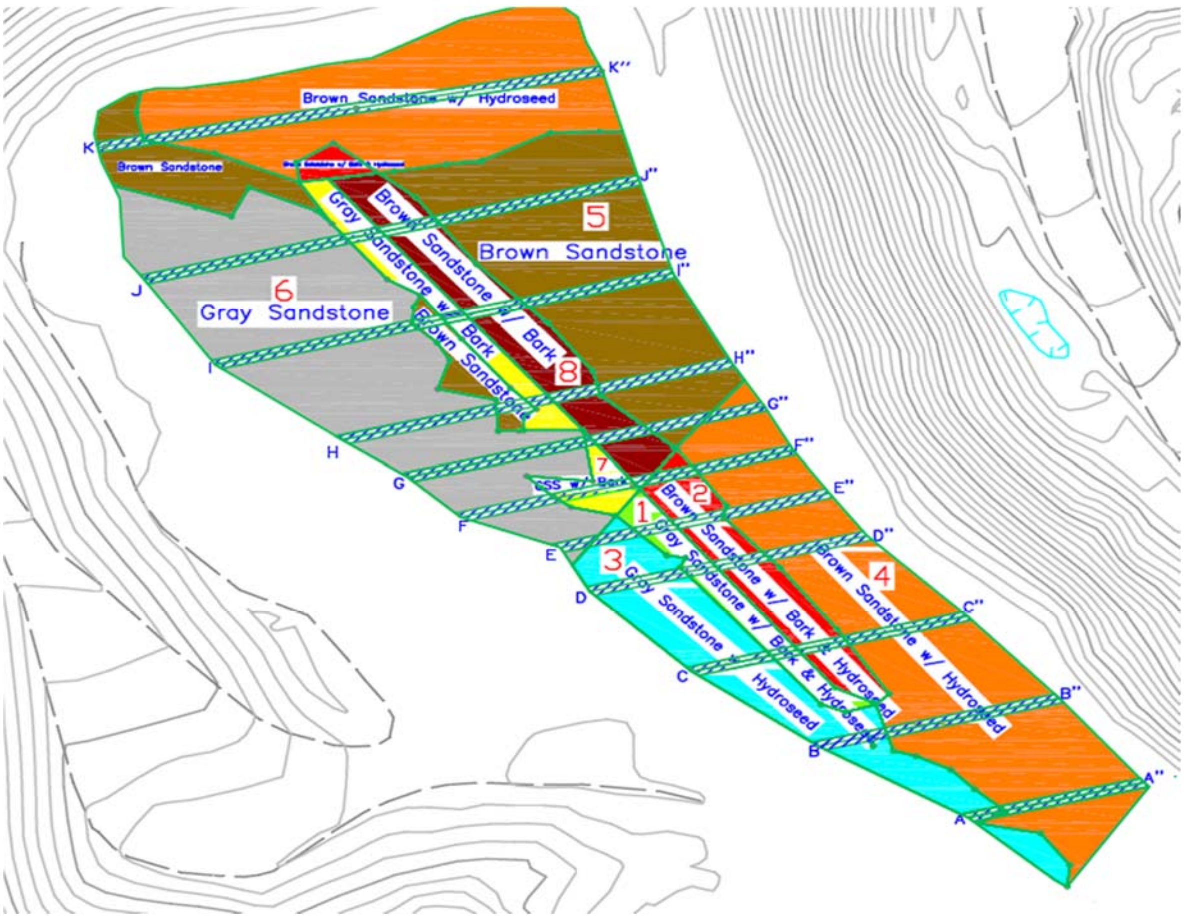

Figure 3-1. Experiment reforestation plots established in 2006 and 2007 at the Birch River Mine in Webster County, West Virginia.

3.2.2 Soils

In addition, soil samples were collected annually. Four samples were collected along transects for each treatment (resulting in 32 samples each year). Soil samples were collected to a depth of 15 cm. Soil samples were air dried, sieved to pass through a 2 mm screen, and, analyzed for pH, electrical conductivity (EC), and Mehlich 1 extractable nutrients. For pH, a mixture 5 g of soil and 5 ml of deionized water (1:1 ratio) was shaken for 1 hour and analyzed with a Fisher Scientific Accumet pH meter model 915 (Thermo Fisher Scientific Inc., Pittsburgh, PA). After pH was determined, 5 ml of deionized water was added to create 1:2 mixture for EC. EC was then determined with a Mettler Toledo S230 EC meter (Mettler-Toledo International Inc., Columbus, OH) after 1 hour. For extractable nutrients, 40 ml of Mehlich 1 solution (0.025 N H_2SO_4 and 0.05 N HCl) was added to 5 g of soil and shaken for 5 minutes. This solution was then passed through Whatman 42 filter paper. The filtered solution was analyzed for aluminum (Al), calcium (Ca), iron (Fe), magnesium (Mg), manganese (Mn), phosphorus (P), potassium (K), and zinc (Zn) with a ICP-OES (Inductively Coupled Plasma-Optical Emission Spectrometer Perkin-Elmer Corp. DV 2100, Norwalk, CT).

3.2.3 Statistical Analysis

Tree volume data was natural log transformed prior to analysis to account for the non-normal distribution. To determine the growth rates of trees over nine years, regression analysis was completed for each treatment. Comparisons were made between two treatments to determine differences in growth rates with Analysis of Covariance (ANCOVA). Specifically, the volume index as an indicator of growth was regressed against the age of trees. If significant, interactions between the treatment group and age (covariate) was detected, then separate intercepts and slopes were reported for a particular comparisons. Because multiple analyses were made, which increases the likelihood of a type I error, a lower Bonferroni adjustment level was used. Since a total of 25 comparisons were being completed, a significance value of 0.002 (0.05/25) was chosen. Stepwise regression analysis was completed for soil properties and average growth for all the years to determine which soil properties are responsible for the growth of trees.

3.3 Results and Discussion

3.2.1 Tree Growth

Growth rates were compared for BMH/BM to B/BH, BMH/BH to B/BM, GMH/GM to G/GH, GMH/GH to G/GM, and, BMH/BM to GMH/GM. Comparisons were made for all species combined, as well as four individual species. Black locust, sugar maple, white oak, and white pine were chosen because they had the highest number of trees for each treatment over each year. Table 3-4 summarizes the numbers of trees that were measured each year in all eight treatments from 2007 to 2015 (except 2013). Total number of trees measured over all the years varied by treatment and ranged from 164 in BMH to 1400 in BH. Table 3-5 shows the average volume for each tree species for each treatment and year (except 2013) and represents all data used for the statistical analysis.

Table 3-6 shows aggregate volume index which is the total number of trees multiplied by the average volume index (Table 3-4 multiplied by Table 3-5). Because of the uneven number of tree species present between treatments and years, this table was created to show that black locust, white oak, and white pine were still considered to be the species with the most growth over all the treatments and years. While the total number of sugar maples present was one of the highest across treatments and years, the aggregate volume of sugar maple was not high. Tulip poplar and sycamore had higher aggregate volume index than sugar maple on many of the treatments.

Figure 3-2 shows show the standard error bars for the average growth over nine years for each treatment. Figure 3-2 also shows that distribution of species varied by treatment. During the initial planting in 2007, the strategy of the planters was to randomly distribute the trees so each treatment does not have the same number of each treatment. The results of the ANCOVA are shown in Table 3-6.

Table 3-4. Numbers of trees measured by species for each treatment from 2007 to 2015 at the Birch River Mine reforestation plots in Webster County, West Virginia.

Treatment	Year	BC	BL	DW	RB	RO	SM	SY	TP	WA	WO	WP	Total
		Species[1]											
		Number of Species											
B	2007	7	9	3	5	5	14	12	6	9	11	12	93
	2008	4	9	1	4	12	10	8	7	12	16	16	99
	2009	4	7	0	2	5	6	9	5	8	11	12	69
	2010	8	17	0	2	9	18	7	4	6	15	16	102
	2011	7	17	0	2	8	16	4	4	7	14	12	91
	2012	7	41	0	1	6	11	8	3	11	6	8	102
	2014	5	69	0	1	7	10	7	6	4	9	8	126
	2015	10	63	0	2	5	20	4	4	3	9	13	133
BH	2007	11	15	7	1	32	21	13	8	15	16	11	150
	2008	14	68	4	0	23	17	11	5	16	15	9	182
	2009	10	12	1	0	24	11	5	4	13	8	9	97
	2010	12	80	2	0	17	5	5	6	8	8	9	152
	2011	15	88	0	0	17	10	6	6	12	16	10	180
	2012	7	94	0	0	15	8	4	6	7	13	7	161
	2014	14	134	0	0	14	11	4	9	5	10	6	207
	2015	14	147	0	0	22	30	5	10	11	17	15	271
BM	2007	2	5	0	2	1	1	0	2	2	1	4	20
	2008	2	8	1	2	1	1	0	2	2	2	6	27
	2009	2	8	0	1	1	1	0	1	2	2	4	22
	2010	2	10	0	1	3	2	0	2	5	2	8	35
	2011	2	13	0	1	1	1	0	3	2	2	6	31
	2012	3	22	0	1	1	1	0	1	2	3	6	40
	2014	3	37	0	3	2	6	1	0	4	9	7	72

		Species[1]											
Treatment	Year	BC	BL	DW	RB	RO	SM	SY	TP	WA	WO	WP	Total
		----------------------------------Number of Species--------------------------------------											
	2015	0	21	0	1	2	1	0	4	2	1	4	36
BMH	2007	0	8	1	0	0	2	4	3	3	3	4	28
	2008	0	3	0	0	0	2	3	1	2	2	3	16
	2009	0	1	0	0	0	2	2	1	2	2	1	11
	2010	0	4	0	0	2	2	2	1	2	2	2	17
	2011	0	8	0	0	0	0	2	0	3	2	1	16
	2012	1	11	0	0	2	1	1		1	2	2	21
	2014	1	6	0	0	1	1	2	1	1	2	2	17
	2015	1	15	0	2	3	3	2	4	1	2	5	38
G	2007	8	7	1	2	10	6	3	5	9	6	11	68
	2008	12	8	2	2	10	8	2	5	5	6	11	71
	2009	5	4	1	2	5	6	1	5	3	3	10	45
	2010	5	7	4	2	12	7	3	10	10	5	11	76
	2011	5	8	2	3	7	2	2	9	8	8	8	62
	2012	3	4	0	0	7	2	1	7	4	6	11	45
	2014	2	6	0	0	9	1	1	4	3	2	9	37
	2015	3	2	0	0	7	3	2	3	3	2	9	34
GH	2007	1	4	1	0	4	4	1	3	1	3	4	26
	2008	1	4	0	0	2	5	0	2	0	3	3	20
	2009	1	3	0	0	1	3	0	1	0	2	2	13
	2010	2	19	0	0	6	7	1	2	4	6	3	50
	2011	0	10	0	0	3	3	0	3	2	3	2	26
	2012	1	22	0	0	1	2	1	1	2	3	2	35
	2014	0	23	0	0	4	8	1	2	1	3	2	44
	2015	1	15	0	1	2	5	1	0	1	3	1	30

Treatment	Year	Species[1] BC	BL	DW	RB	RO	SM	SY	TP	WA	WO	WP	Total
		---Number of Species---											
GM	2007	2	4	1	1	6	3	0	3	6	2	2	30
	2008	3	4	1	1	7	5	0	6	6	2	2	37
	2009	2	3	0	0	4	5	0	4	4	1	1	24
	2010	4	9	1	1	4	8	1	7	6	4	2	47
	2011	3	13	1	1	5	4	3	8	4	4	5	51
	2012	4	7	0	1	3	1	0	1	6	1	2	26
	2014	2	17	0	0	4	3	2	3	4	2	1	38
	2015	2	18	0	0	6	5	1	7	5	2	3	49
GMH	2007	2	0	1	0	4	4	5	1	1	2	1	21
	2008	1	1	0	0	3	2	2	0	1	2	1	13
	2009	1	0	0	0	3	2	1	0	1	2	1	11
	2010	3	7	0	0	2	2	2	1	1	2	2	22
	2011	3	6	0	0	2	1	2	1	1	2	2	20
	2012	6	2	0	0	2	0	3	5	0	3	2	23
	2014	3	13	0	0	2	1	2	0	1	2	1	25
	2015	5	18	0	0	1	3	2	1	1	2	4	37

[1] BC = black cherry; BL = black locust; DW = dogwood; RB = redbud; RO = red oak; SM = sugar maple; SY = sycamore; TP = tulip poplar; WA = white ash; WO = white oak; WP = white pine.

Table 3-5. Average tree volume index by species, treatments, and year at the Birch River Mine site in Webster County, WV.

Treatment	Year	Species[1] BC	BL	DW	RB	RO	SM	SY	TP	WA	WO	WP	All
		--- cm^3 ---											
B	2007	11	61	1	4	17	4	18	25	11	15	5	16
	2008	93	184	2	1	34	8	28	60	21	30	23	43

Treatment	Year	BC	BL	DW	RB	RO	SM	SY	TP	WA	WO	WP	All
		Species[1]											
		cm^3											
	2009	173	732	NA	47	113	30	94	87	142	66	189	175
	2010	1070	1655	NA	37	358	59	152	282	833	214	493	582
	2011	2407	4171	NA	71	1009	110	519	794	9585	507	1053	2086
	2012	7380	3528	NA	5492	3612	480	2674	4948	2508	2180	4073	3316
	2014	10045	5020	NA	9094	4312	228	3625	12313	749	6334	4583	5032
	2015	6961	7341	NA	7751	6318	302	6589	8369	992	4358	12387	6378
BH	2007	14	37	1	4	20	5	24	33	20	9	7	17
	2008	57	75	2	NA	55	6	60	29	36	23	19	50
	2009	199	2065	2	NA	117	13	65	128	134	95	99	340
	2010	363	1113	15	NA	242	31	390	307	270	258	276	712
	2011	643	2881	NA	NA	452	33	1033	1599	364	331	707	1687
	2012	3516	9250	NA	NA	2020	460	2412	4203	1121	1340	2424	6243
	2014	3651	8493	NA	NA	5226	162	1879	9143	1005	1696	9471	6921
	2015	5846	14991	NA	NA	6194	314	9879	20349	336	5127	20732	11387
BM	2007	12	24	NA	4	15	2	NA	17	5	7	5	12
	2008	83	71	1	7	38	2	NA	50	7	9	7	36
	2009	485	477	NA	37	104	18	NA	963	77	5	26	281
	2010	3972	1969	NA	84	186	46	NA	2311	377	195	171	1047
	2011	9382	3837	NA	325	687	81	NA	5711	701	534	244	2929
	2012	23444	5228	NA	1625	2440	477	NA	1981	3904	3749	1931	5563
	2014	16119	9666	NA	2338	7643	60	38093	NA	3276	8054	12419	8879
	2015	NA	13276	NA	2695	10646	356	NA	45209	1428	2700	22225	16068
BMH	2007	NA	49	1	NA	NA	8	21	9	26	15	4	24
	2008	NA	54	NA	NA	NA	12	37	40	8	18	16	27
	2009	NA	758	NA	NA	NA	26	82	163	52	46	332	151

		Species[1]											
Treatment	Year	BC	BL	DW	RB	RO	SM	SY	TP	WA	WO	WP	All
		cm^3											
	2010	NA	2123	NA	NA	210	8	331	658	190	218	464	705
	2011	NA	3093	NA	NA	NA	NA	428	NA	609	714	3853	2044
	2012	366	11583	NA	NA	1594	488	13828	NA	790	1094	6896	7717
	2014	5362	9984	NA	NA	7500	433	28333	42738	2210	3100	23460	13408
	2015	17523	22477	NA	2100	10759	14519	59872	46288	1825	11755	49086	26589
G	2007	11	58	4	10	13	5	9	31	16	11	7	17
	2008	18	105	3	1	18	8	22	34	32	14	12	27
	2009	32	89	4	4	29	8	23	51	53	18	27	33
	2010	39	138	11	5	38	10	258	114	60	97	70	72
	2011	16	946	11	4	39	7	1028	207	176	154	106	248
	2012	377	2155	NA	NA	361	93	8784	605	932	114	629	818
	2014	15	35	NA	NA	52	33	0	94	765	43	291	165
	2015	0	27	NA	NA	64	2	5	108	30	0	233	89
GH	2007	6	14	0	NA	25	4	23	16	13	20	9	14
	2008	10	34	NA	NA	5	3	NA	31	NA	19	18	17
	2009	4	113	NA	NA	14	3		65	NA	5	43	40
	2010	336	470	NA	NA	120	7	3	34	137	20	115	229
	2011	NA	271	NA	NA	191	9	NA	37	58	61	260	163
	2012	64	2003	NA	NA	16	43	208	149	1262	111	5372	1663
	2014	NA	2517	NA	NA	826	1252	5043	20616	27	272	2168	2788
	2015	2190	1809	NA	179	373	35	90	NA	73	177	662	1059
GM	2007	20	23	2	5	25	4	NA	36	11	21	7	18
	2008	51	86	0	1	30	28	NA	124	22	5	19	48
	2009	314	320	NA	NA	84	8	NA	737	196	7	27	239
	2010	1427	800	14	41	496	114	411	2163	460	264	367	765

Treatment	Year	BC	BL	DW	RB	RO	SM	SY	TP	WA	WO	WP	All
		Species[1]											
		cm^3											
	2011	3961	1275	31	126	1866	86	5116	3740	785	696	990	1852
	2012	6988	4913	NA	1249	3503	633	NA	30011	2056	1067	4586	4897
	2014	14996	6475	NA	NA	11201	1449	17366	57229	1284	6198	9046	11111
	2015	27690	15459	NA	NA	16079	573	19752	37186	1996	6677	20996	16313
GMH	2007	10	NA	0	NA	14	3	24	23	16	11	1	13
	2008	20	5	NA	NA	6	4	33	NA	6	27	6	14
	2009	65	NA	NA	NA	24	4	142	NA	36	159	60	64
	2010	92	76	NA	NA	65	31	700	8	200	405	285	182
	2011	530	460	NA	NA	442	76	3835	3992	309	1015	1116	1077
	2012	7825	121	NA	NA	726	NA	11789	13330	NA	3104	4358	7334
	2014	5913	9375	NA	NA	2618	580	34893	NA	4715	22347	17956	11303
	2015	5147	16364	NA	NA	6848	62	66204	875	50	36846	28851	17561

[1] See footnote for Table 3-4 for species abbreviations.

Table 3- 6. Aggregate tree volume index by species, treatments, and year at the Birch River Mine site in Webster County, WV.

Treatment	Year	BC	BL	DW	RB	RO	SM	SY	TP	WA	WO	WP	All
		Species[1]											
		cm^3											
B	2007	74	549	3	19	84	55	215	149	96	160	57	1461
	2008	373	1655	2	6	412	84	224	421	248	476	373	4274
	2009	690	5123	NA	95	564	178	845	433	1136	729	2264	12057
	2010	8561	28129	NA	73	3224	1068	1065	1129	5000	3209	7895	59352
	2011	16850	70911	NA	143	8076	1762	2076	3177	67094	7098	12635	189823
	2012	51661	144642	NA	5492	21671	5283	21390	14845	27583	13083	32583	338234
	2014	50223	346400	NA	9094	30181	2281	25372	73875	2994	57002	36663	634086
	2015	69614	462479	NA	15502	31588	6036	26355	33474	2976	39219	161026	848269

Treatment	Year	BC	BL	DW	RB	RO	SM	SY	TP	WA	WO	WP	All
		Species[1]											
		cm³											
BH	2007	159	549	7	4	643	104	312	264	306	140	76	2565
	2008	793	5121	8	NA	1259	110	659	143	581	342	173	9187
	2009	1995	24777	2	NA	2797	139	323	513	1743	760	887	32993
	2010	4355	89058	30	NA	4117	153	1949	1840	2160	2062	2482	108205
	2011	9649	253557	NA	NA	7683	331	6195	9596	4374	5295	7067	303748
	2012	24611	869490	NA	NA	30294	3679	9648	25221	7844	17423	16971	1005181
	2014	51119	1138041	NA	NA	73168	1783	7517	82289	5027	16960	56827	1432730
	2015	81838	2203677	NA	NA	136261	9434	49396	203493	3696	87155	310977	3085927
BM	2007	24	119	NA	8	15	2	NA	34	11	7	20	240
	2008	166	568	1	14	38	2	NA	100	13	18	43	965
	2009	969	3816	NA	37	104	18	NA	963	154	11	104	6177
	2010	7943	19686	NA	84	557	92	NA	4621	1886	391	1372	36633
	2011	18763	49885	NA	325	687	81	NA	17133	1403	1069	1463	90809
	2012	70331	115008	NA	1625	2440	477	NA	1981	7808	11247	11586	222502
	2014	48357	357642	NA	7015	15285	360	38093	NA	13105	72490	86931	639277
	2015	NA	278803	NA	2695	21291	356	NA	180837	2856	2700	88901	578439
BMH	2007	NA	395	1	NA	NA	16	83	26	79	44	15	659
	2008	NA	162	NA	NA	NA	23	111	40	16	35	48	435
	2009	NA	758	NA	NA	NA	53	163	163	103	91	332	1664
	2010	NA	8491	NA	NA	421	16	662	658	381	436	927	11991
	2011	NA	24743	NA	NA	NA	NA	NA	NA	1827	1428	3853	32707
	2012	366	127413	NA	NA	3188	488	13828	NA	790	2188	13792	162052
	2014	5362	59906	NA	NA	7500	433	56666	42738	2210	6201	46921	227937
	2015	17523	337152	NA	4200	32278	43557	119744	185152	1825	23511	245429	1010371

Treatment	Year	BC	BL	DW	RB	RO	SM	SY	TP	WA	WO	WP	All
		Species[1]											
		------ cm^3 ------											
G	2007	92	406	4	20	133	28	28	154	148	66	77	1154
	2008	215	843	6	2	178	64	44	172	161	86	136	1907
	2009	160	356	4	8	143	48	23	253	160	54	269	1500
	2010	193	968	42	11	453	70	774	1139	600	486	767	5503
	2011	80	7567	22	13	272	15	2057	1860	1410	1228	849	15375
	2012	1131	8622	NA	NA	2526	185	8784	4238	3727	683	6917	36813
	2014	31	210	NA	NA	466	33	0	377	2296	86	2621	6119
	2015	0	54	NA	NA	447	5	10	323	89	0	2098	3026
GH	2007	6	55	0	NA	100	18	23	49	13	60	35	358
	2008	10	135	NA	NA	10	17	NA	61	NA	56	54	344
	2009	4	338	NA	NA	14	9	NA	65	NA	9	86	524
	2010	673	8936	NA	NA	718	50	3	67	546	118	346	11458
	2011	NA	2705	NA	NA	574	27	NA	112	116	183	520	4237
	2012	64	44075	NA	NA	16	87	208	149	2524	332	10745	58201
	2014	NA	57885	NA	NA	3304	10017	5043	41231	27	817	4337	122661
	2015	2190	27135	NA	179	746	176	90	NA	73	530	662	31780
GM	2007	40	92	2	5	151	13	NA	108	67	42	14	535
	2008	153	343	0	1	207	141	NA	742	134	10	38	1768
	2009	629	961	NA	NA	336	38	NA	2950	784	7	27	5731
	2010	5709	7200	14	41	1982	911	411	15139	2760	1054	734	35955
	2011	11884	16574	31	126	9331	344	15347	29919	3140	2783	4948	94428
	2012	27952	34391	NA	1249	10509	633	NA	30011	12337	1067	9173	127321
	2014	29992	110071	NA	NA	44804	4347	34732	171687	5135	12397	9046	422212
	2015	55380	278265	NA	NA	96472	2864	19752	260299	9978	13354	62988	799352
GMH	2007	20	NA	0	NA	55	13	120	23	16	21	1	269

Treatment	Year	BC	BL	DW	RB	RO	SM	SY	TP	WA	WO	WP	All
		Species[1]											
		cm³											
	2008	20	5	NA	NA	17	7	65	NA	6	53	6	179
	2009	65	NA	NA	NA	71	9	142	NA	36	317	60	701
	2010	277	533	NA	NA	130	63	1401	8	200	810	571	3993
	2011	1591	2762	NA	NA	884	76	7671	3992	309	2030	2232	21546
	2012	46950	241	NA	NA	1451	NA	35366	66652	NA	9311	8717	168688
	2014	17739	121871	NA	NA	5235	580	69785	NA	4715	44694	17956	282575
	2015	25733	294557	NA	NA	6848	186	132408	875	50	73692	115405	649754

[1] See footnote for Table 3-4 for species abbreviations.

Table 3-7. Statistical results for comparing the average growth rates of all species combined, black locust, sugar maple, white oak, and white pine over nine years at the Birch River Mine reforestation plots in Webster County, West Virginia.

Species/Comparison		Intercept	Slope	P[1]	R^2
All					
	BMH/BM	1.82	0.78	**0.0013**	0.43
	B/BH	2.07	0.65		
BL					
	BMH/BM	3.38	0.55	0.8143	0.27
	B/BH	3.01	0.57		
SM					
	BMH/BM	0.71	0.56	0.0423	0.17
	B/BH	1.53	0.26		
WO					
	BMH/BM	0.94	0.94	0.0204	0.70
	B/BH	1.56	0.79		
WP					
	BMH/BM	-0.41	1.20	**<0.0001**	0.85
	B/BH	1.29	0.94		
All					
	BMH/BH	1.84	0.72	**<0.0001**	0.43
	B/BM	2.32	0.60		
BL					
	BMH/BH	2.33	0.79	**<0.0001**	0.33
	B/BM	4.68	0.25		
SM					
	BMH/BH	1.28	0.26	0.5144	0.16
	B/BM	1.60	0.32		
WO					
	BMH/BH	1.35	0.73	0.1476	0.70
	B/BM	1.51	0.83		
WP					
	BMH/BH	0.7	1.05	0.1387	0.83
	B/BM	1.00	0.96		
All					
	GMH/GM	1.72	0.79	**<0.0001**	0.44
	G/GH	2.19	0.26		
BL					
	GMH/GM	2.20	0.70	**<0.0001**	0.39
	G/GH	3.46	0.25		

Species/Comparison		Intercept	Slope	P[1]	R^2
SM					
	GMH/GM	0.91	0.45	0.0087	0.22
	G/GH	1.37	0.11		
WO					
	GMH/GM	0.91	0.98	**<0.0001**	0.54
	G/GH	2.23	-0.004		
WP					
	GMH/GM	0.45	1.12	**<0.0001**	0.68
	G/GH	1.69	0.44		
All					
	GMH/GH	1.33	0.65	**0.0011**	0.26
	G/GM	2.03	0.46		
BL					
	GMH/GH	1.97	0.62	0.1538	0.29
	G/GM	3.15	0.47		
SM					
	GMH/GH	0.57	0.30	0.6117	0.14
	G/GM	1.50	0.24		
WO					
	GMH/GH	1.31	0.54	0.2898	0.13
	G/GM	1.85	0.29		
WP					
	GMH/GH	0.83	1.00	**0.0005**	0.57
	G/GM	1.45	0.53		
All					
	BMH/BM	1.54	0.89	0.9683	0.66
	GMH/GM	1.07	0.89		
BL					
	BMH/BM	2.78	0.74	0.1302	0.59
	GMH/GM	0.21	0.97		
SM					
	BMH/BM	-0.04	0.87	0.0841	0.64
	GMH/GM	0.31	0.46		
WO					
	BMH/BM	1.43	0.82	0.0438	0.93
	GMH/GM	0.41	1.06		
WP					
	BMH/BM	0.19	1.19	0.9743	0.87
	GMH/GM	0.10	1.18		

[1] Bold indicates significant difference between growth rates.

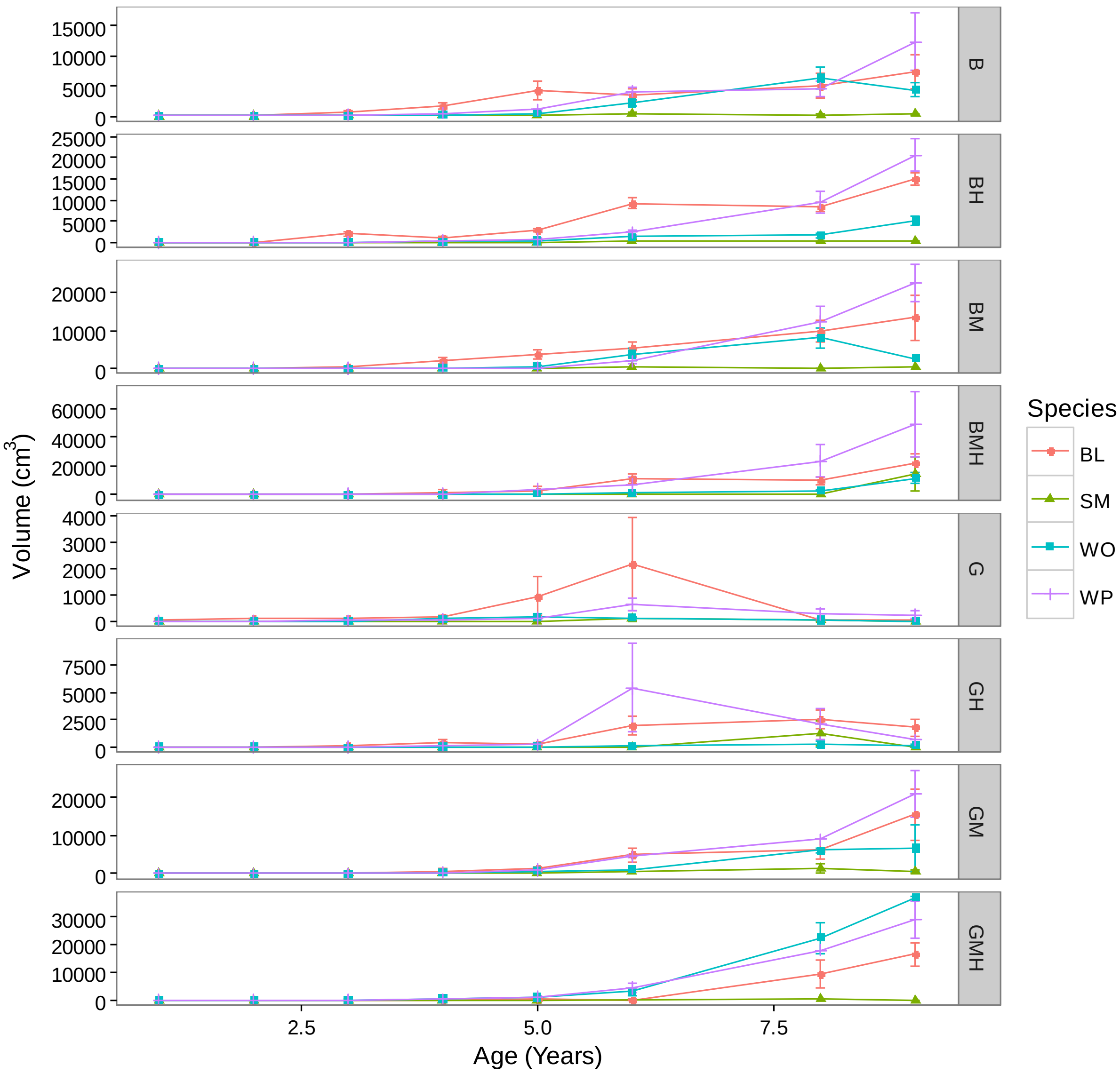

Figure 3-2. Average growth and standard error bars from ages 1 to 9 for all trees on eight treatments at the Birch River Mine reforestation plots in Webster County, West Virginia. Note that the scales for volume are different for each treatment.

When comparing all species, significant differences were found for all comparisons except for BM/BMH to GM/GMH. This shows that the addition of mulch to gray sandstone significantly increases the growth of the trees and makes the gray sandstone as good as mulch-amended brown sandstone. For both gray and brown sandstone, adding mulch and hydroseeding significantly increased the growth of trees when looking at all species together. Figure 3-3 shows the comparisons that were significantly different for all species. The increases from hydroseeding and mulching were greater on gray sandstone than on brown sandstone. When looking at the brown mulching treatments, growth rates for all species combined were increased from 0.65 to 0.78 cm^3/year and for brown hydroseeding treatments, the growth was increased from 0.6 to 0.72 cm^3/year. For the gray sandstone, the mulching treatment increased the growth rate from 0.26 to 0.79 cm^3/year and the hydroseeding treatment increased the growth rates from 0.46 to 0.65 cm^3/year. Increases in growth rates from mulching and hydroseeding were expected due to increase in organic matter and nutrients, as well as other beneficial effects of soil amendments.

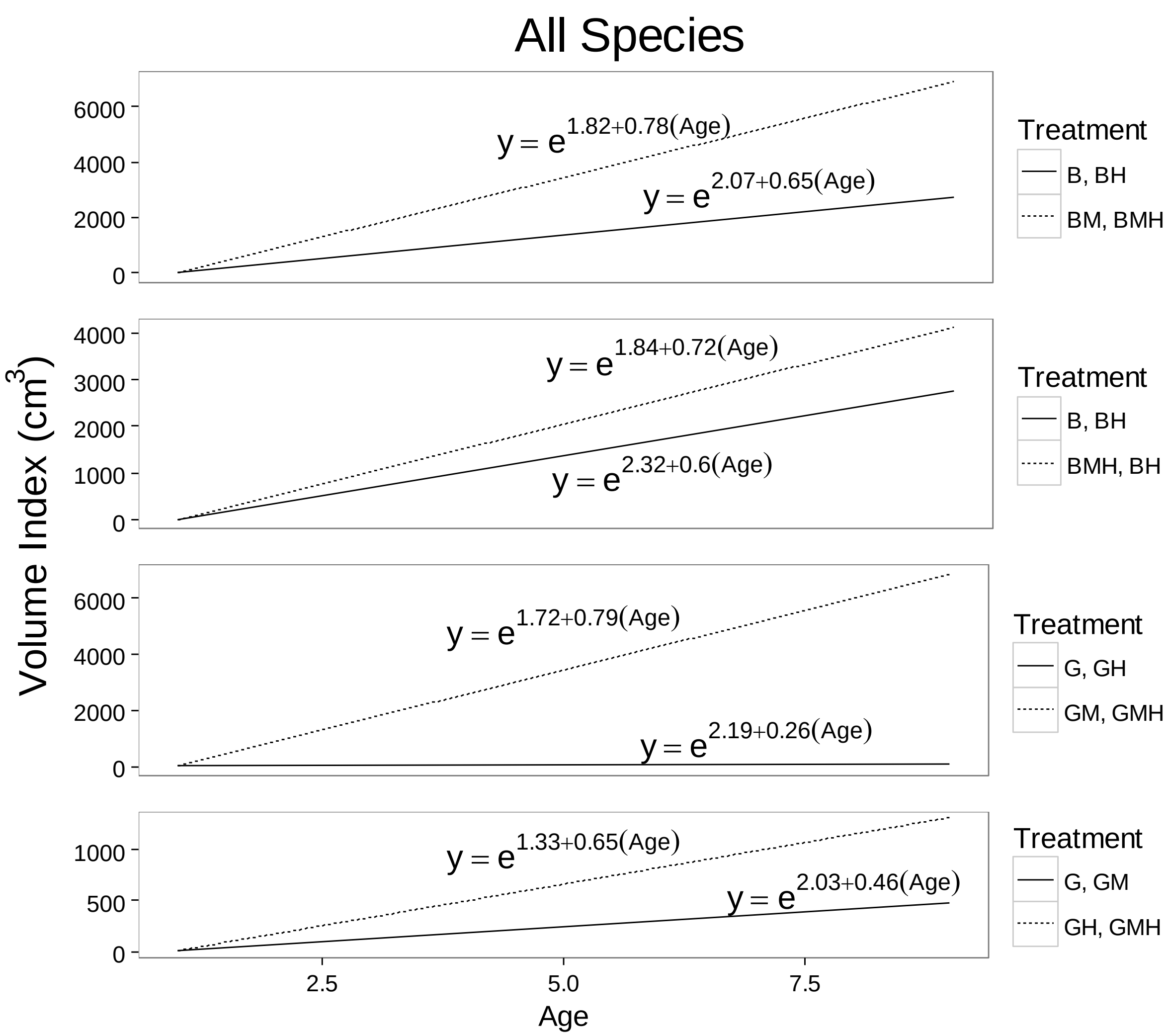

Figure 3-3. Treatment comparisons showing significant differences of average growth rates for all trees species combined at the Birch River Mine reforestation plots in Webster County, West Virginia.

Figure 3-4 shows the comparisons that were significantly different for black locust. The growth of black locust was significantly different between the brown hydroseed treatments and the non-hydroseed treatments and between the gray mulch treatments and the non-mulched treatments.

The growth rate increased from 0.25 to 0.73 cm^3/year with hydroseeding on the brown sandstone and from 0.28 to 0.70 cm^3/year with the mulch treatment on the gray sandstone. Black locust had high survival and good growth on both brown and gray sandstone even without soil amendments and is considered an early successional species (Miller et al., 2012; Wilson-Kokes et al., 2013a). Black locust grows well on mine sites because it is tolerant of the harsh conditions of mine soils and can grow across a broad range of pH conditions and can tolerate coarse-textured soils. It belongs to the Fabaceae family and has nitrogen-fixing capabilities due to Rhizobium bacteria forming nodules. It also is a prolific seed producer early in its growth cycle, which are spread rapidly by birds and other vectors. Black locust has rapid juvenile growth and is able to readily produce sprouts from roots. Spouts of black locust can grow more rapidly than seedlings (Huntley, 1990). As shown in Figure 3-2, the standard error for black locust is large, which is due to the large amount of seedling sprouts. Wilson-Kokes et al. (2013a) also found black locust to have a wide variation in average volumes. Black locust is also known to be a common volunteer species on mine sites due to its rapid recruitment from seeds from on-site and off-site trees (Evans et al., 2013).

The growth of sugar maple was not significantly different for any of the comparisons (Table 3-6). Sugar maple grows on a variety of sites and is slow growing (Godman et al., 1990). Sugar maple can tolerate a range of pH (5.5 to 7.3). Sugar maple has been found to have low survival and poor growth on mine sites (Wilson-Kokes at al., 2014). In a study by Miller et al. (2012), the height of sugar maple was not different between brown and gray sandstone treatments after the second growing season.

White oak growth was significantly different when comparing gray mulch treatments to non-mulch treatments. The growth rate of white oak was increased from -0.004 to 0.98 cm^3/year on gray sandstone when mulch was added. White oak has been found to grow well on brown sandstone (Miller et al., 2012) which could explain why the mulch and hydroseed treatments on the brown sandstone did not have a significant effect on the growth rate.

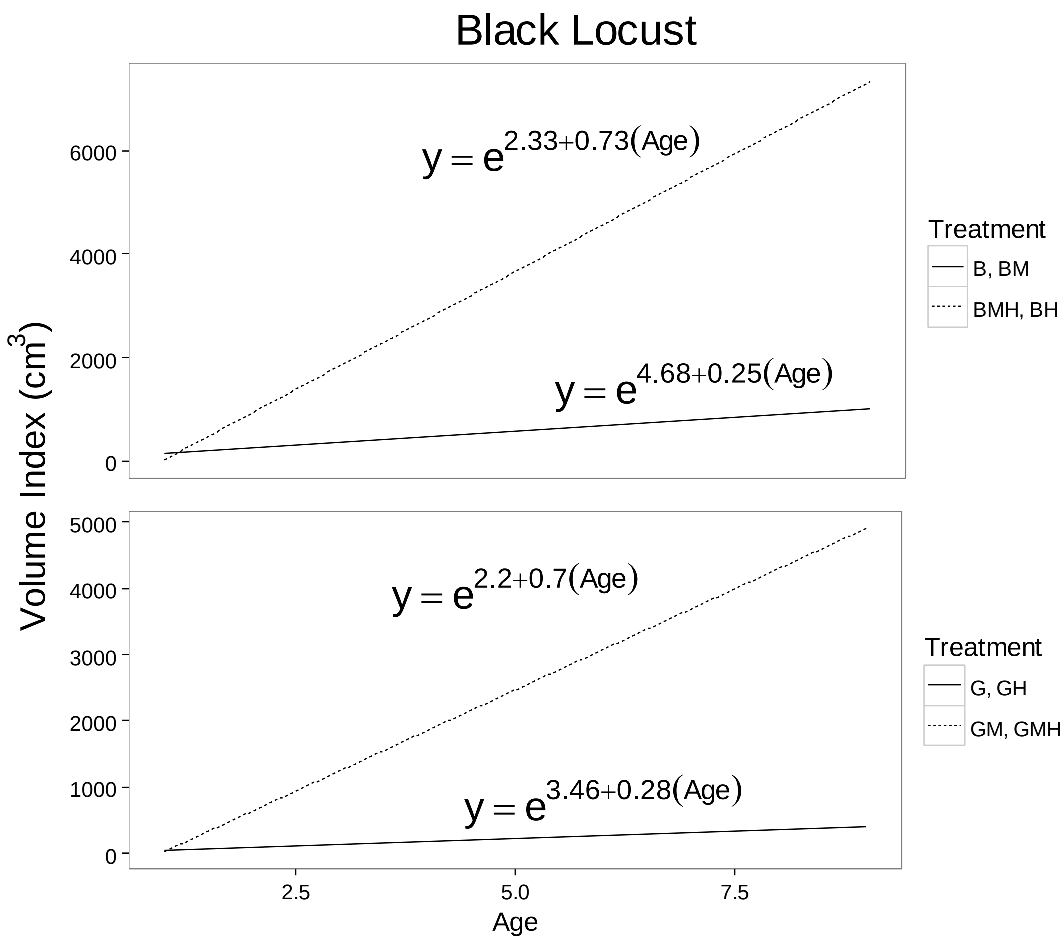

Figure 3- 4. Treatment comparisons showing significant differences of average growth rates for black locust at the Birch River Mine reforestation plots in Webster County, West Virginia.

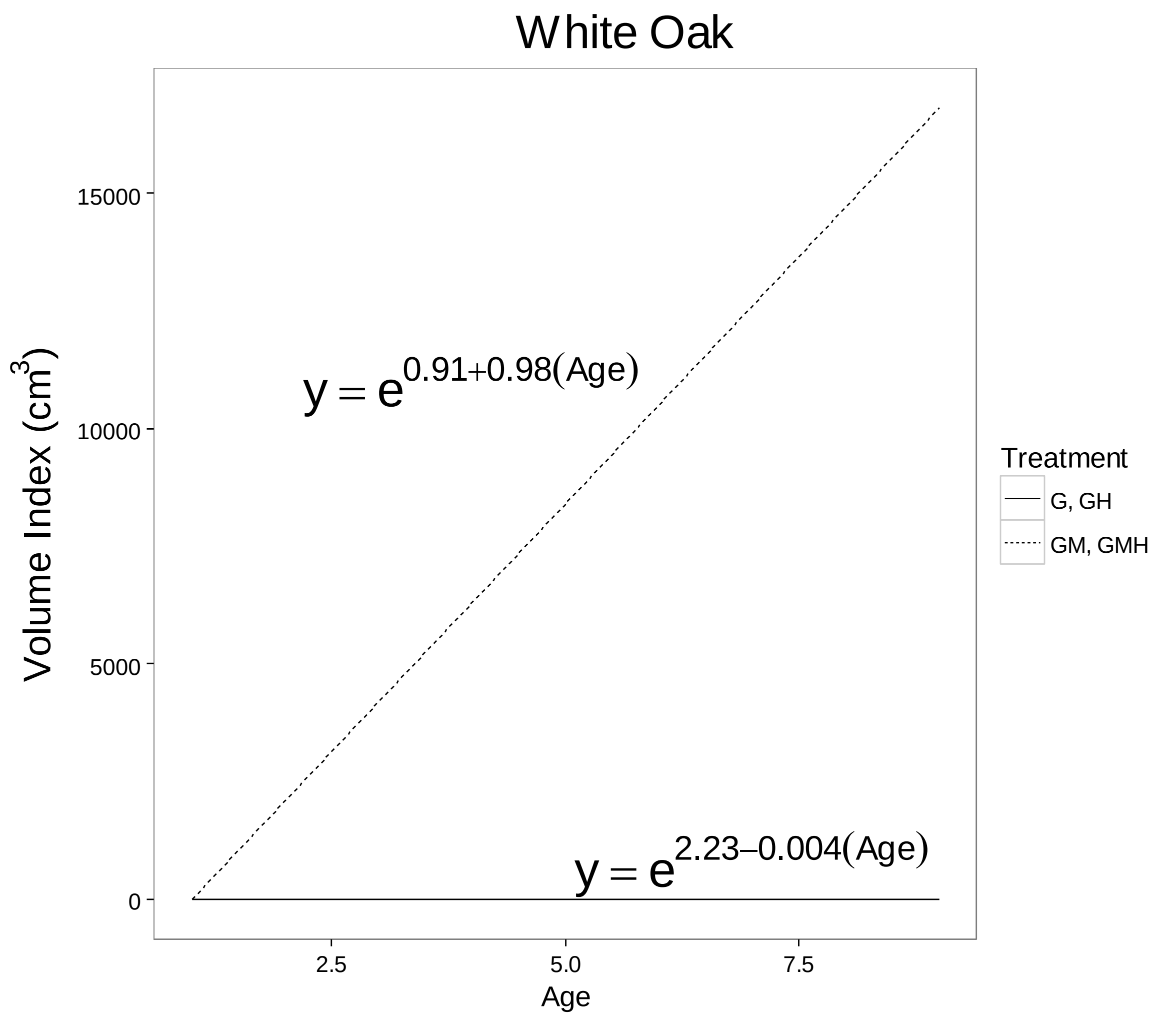

Figure 3- 5. Treatment comparisons showing significant differences of average growth rates for white oak at the Birch River Mine reforestation plots in Webster County, West Virginia.

The growth of white pine was significantly different when comparing the mulch treatments to non-mulched treatments for both brown and gray sandstone, as well as when comparing the gray hydroseed to the non-hydroseed treatment. For brown sandstone, the mulch treatment increased the growth rate from 0.94 to 1.2 cm^3/year. For gray sandstone, the mulch treatment increased the growth rate from 0.44 to 1.12 cm^3/year. The growth rate of white pine on gray sandstone was increased from 0.53 to 1.00 cm^3/year when hydroseeding was included as a treatment. Wilson-Kokes et al. (2014) also found that the growth of white pine on gray sandstone was increased with mulch and/or hydroseeding treatments. White pine has been found to be as productive on mine sites as in natural regions of the Appalachians (Torbet et al., 2000). High soil fines was found to positively increase white pine growth on mine sites (Zipper et al., 2013).

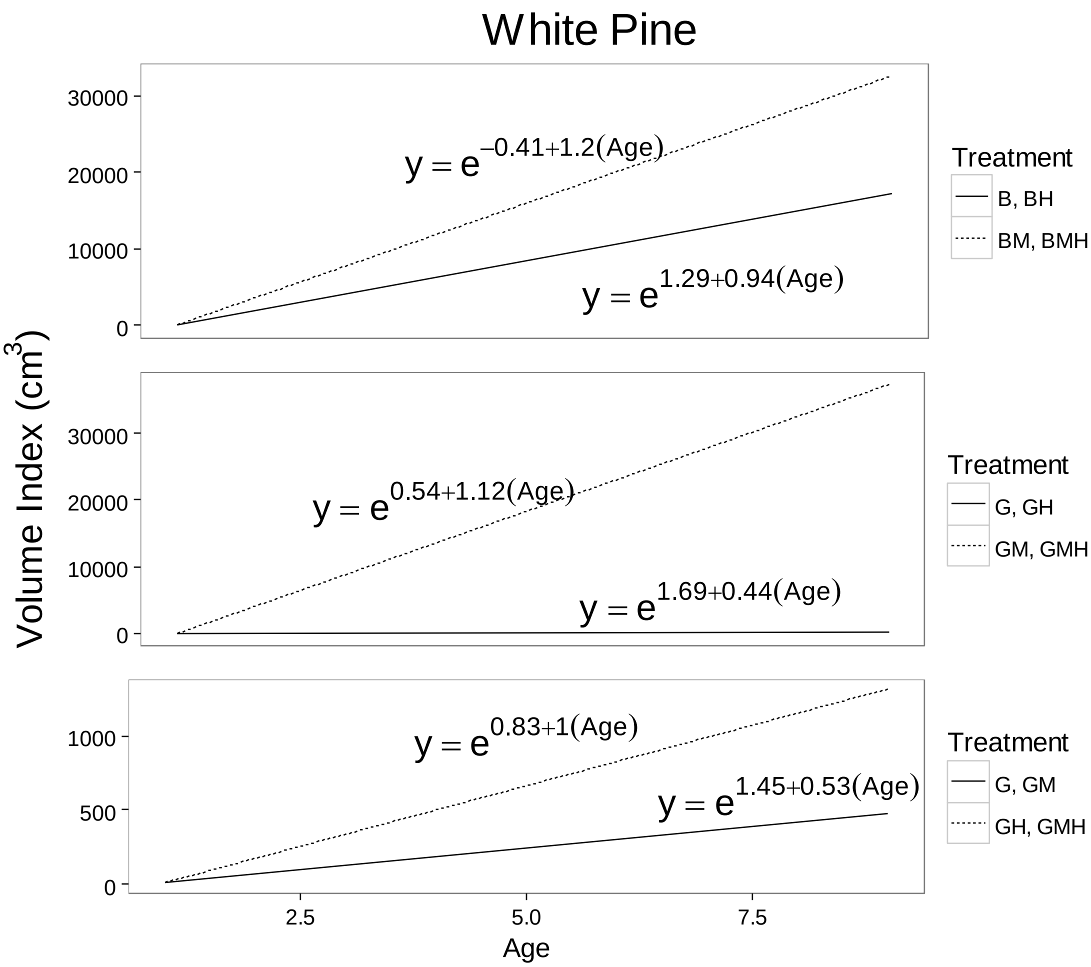

Figure 3- 6. Treatment comparisons showing significant differences of average growth rates for white pine at the Birch River Mine reforestation plots in Webster County, West Virginia.

3.2.2 Soils

Table 3-7 shows the average values for all the soil properties of all treatments across years (except 2013) at the Birch River mine site. The pH for the brown without mulch treatments (B and BH) were within the expected values and ranged from 4.7 on B in 2008 to 5.5 on BH in 2012. For the mulch-treated brown plots (BM and BMH), the pH values were higher and ranged from 6.4 in BMH in 2012 to 8.1 in BMH in 2008. The pH for BM and BMH was higher than the other brown plots because the bark mulch had limestone added at the sawmill. The pH for all the gray sandstone plots were all within the expected values and ranged from 6.4 in G in 2014 to 8.0 in GM in 2015 and GMH in 2012. EC values over all the years and the treatments were very low. Percent fines increased in all the treatments from 2008 to 2015 and the increases ranged from 17% in G to 27% in GH. For the extractable nutrients, a lot of variance was seen over the years. For example, Al in BH ranged from 176 mg/kg in 2015 to 850 mg/kg in 2008.

Table 3-8 shows the results of the stepwise regression when tree growth was correlated to soil properties. For all species together, percent fines, Fe, Mg, and Ca were selected as being correlated to growth. Percent fines and Fe were selected for black locust and white pine, while percent fines and calcium were chosen for sugar maple and white oak. While the stepwise regression selected some soil properties as being responsible for growth, the R^2 values were low. The high variability in the soil property data is the likely reason for the low R^2 values. Figures 3-7 to 3-10 show the volume of all trees and the selected soil properties. These figures also show that even though these properties were selected as being responsible for tree growth, the data were very scattered. The trend between volume growth and soil properties are difficult to discern in Figures 3-7 to 3-10. This is due to the high variability in soils properties, as well as growth among years. The purpose of showing the stepwise regression analysis was to show that even though there was high variability, the results of the analysis were still consistent with other studies.

Table 3- 8. Average values for soil properties for all treatments from 2008 to 2015 at the Birch River Mine reforestation plots in Webster County, West Virginia.

Treatment	Year	pH	EC	Fines	Al	Fe	Mn	P	Zn	Mg	Ca	K
			-dS m^{-1}-	-%-	----------------mg kg^{-1}				--------------	---------cmol$_c$ kg^{-1}--------		
B	2008	4.7	0.12	58	NA	384	144	22	20.5	7.5	5.5	0.7
	2009	4.8	0.05	53	182	89	82	23	22.5	3.5	3.5	0.4
	2010	5.0	0.08	38	231	87	87	21	25.7	5.4	4.2	0.5
	2011	5.1	0.04	47	268	116	77	17	23.9	3.7	3.8	0.4
	2012	5.0	0.06	63	489	132	15	10	3.5	3.4	2.8	0.3
	2014	5.0	0.01	50	448	209	NA	18	NA	4.1	5.5	0.5
	2015	4.8	0.03	76	97	20	6	2	6.4	0.4	0.4	0.1
BH	2008	4.8	0.06	47	NA	497	168	15	15.7	2.5	2.0	0.7
	2009	5.4	0.07	49	850	258	170	24	23.7	4.0	5.3	0.5
	2010	5.3	0.08	42	543	174	88	42	14.7	3.6	3.7	0.4
	2011	5.4	0.04	47	417	177	101	26	22.9	3.8	4.2	0.4
	2012	5.5	0.07	55	412	142	102	35	19.4	4.2	3.9	0.4
	2014	5.3	0.01	40	356	229	NA	59	NA	4.4	7.5	0.8
	2015	4.9	0.02	59	176	31	14	3	2.6	0.4	0.4	0.1
BM	2008	7.1	0.28	25	NA	314	217	32	33.3	7.4	25.7	0.9
	2009	7.5	0.31	37	238	81	308	13	13.3	12.7	94.3	0.7
	2010	7.6	0.42	31	130	86	355	14	1.9	18.8	77.7	1.5
	2011	7.7	0.38	34	156	70	202	17	7.9	9.1	100.3	0.6
	2012	7.2	0.28	50	58	22	27	4	1.2	9.2	77.9	0.2
	2014	6.6	0.04	45	151	54	NA	21	NA	12.1	207.2	0.8
	2015	7.9	0.24	51	<1	2	18	2	0.3	1.5	8.8	0.2
BMH	2008	8.1	0.39	27	NA	37	273	7	9.2	14.2	81.4	1.4
	2009	7.8	0.30	41	145	142	339	15	14.6	12.6	91.0	0.7

Treatment	Year	pH	EC	Fines	Al	Fe	Mn	P	Zn	Mg	Ca	K
			-dS m^{-1}-	-%-	----------------mg kg^{-1}--------------					---------cmol$_c$ kg^{-1}--------		
	2010	6.7	0.35	33	260	95	461	16	6.6	19.7	78.4	1.4
	2011	7.7	0.34	37	31	12	137	5	3.4	6.4	59.4	0.3
	2012	6.4	0.18	57	528	168	182	22	12.5	7.0	41.4	1.1
	2014	7.2	0.03	38	43	26	NA	19	NA	12.2	209.8	1.3
	2015	7.8	0.21	48	6	4	40	3	1.4	2.4	10.8	0.1
G	2008	7.9	0.12	42	NA	1608	336	96	26.1	5.9	7.5	0.7
	2009	7.8	0.08	41	84	375	216	21	20.9	4.7	7.7	0.3
	2010	7.4	0.09	25	118	406	190	92	11.4	5.4	7.3	0.5
	2011	7.5	0.05	37	73	184	118	61	11.6	3.5	4.5	0.3
	2012	7.0	0.11	40	51	104	19	33	1.5	3.7	4.0	0.1
	2014	6.4	0.00	47	115	133	NA	57	NA	3.7	5.1	0.3
	2015	7.5	0.06	59	23	54	42	20	2.2	0.9	1.4	0.1
GH	2008	7.4	0.12	34	NA	3270	510	101	30.2	10.1	12.9	0.9
	2009	7.8	0.11	37	83	359	193	23	22.9	4.7	8.5	0.4
	2010	7.1	0.16	27	134	543	274	106	19.7	6.0	9.0	0.7
	2011	7.3	0.04	43	89	255	144	46	17.6	3.7	4.6	0.3
	2012	7.7	0.09	25	85	280	29	52	3.0	4.6	5.7	0.2
	2014	6.5	0.01	51	111	117	NA	30	NA	3.3	6.8	0.4
	2015	7.3	0.06	61	23	75	41	11	2.6	0.9	1.3	0.1
GM	2008	7.0	0.28	34	NA	1034	589	38	28.5	19.0	57.1	1.0
	2009	7.5	0.33	42	206	65	276	17	17.3	12.0	103.3	0.6
	2010	7.6	0.53	25	0	23	233	15	0.3	15.4	85.2	1.3
	2011	7.7	0.35	38	89	20	180	4	4.0	7.2	65.5	0.3
	2012	7.9	0.37	59	0	5	13	1	0.1	6.5	72.0	0.1
	2014	7.0	0.04	40	167	84	NA	29	NA	12.1	183.0	0.7
	2015	8.0	0.19	58	34	22	36	3	2.0	1.9	8.9	0.1

Treatment	Year	pH	EC	Fines	Al	Fe	Mn	P	Zn	Mg	Ca	K
			-dS m^{-1}-	-%-	----------------mg kg^{-1}--------------					---------$cmol_c$ kg^{-1}--------		
GMH	2008	6.9	0.40	32	NA	454	873	10	10.1	24.5	91.6	1.4
	2009	7.0	0.29	35	727	185	321	12	12.2	9.6	76.4	0.6
	2010	7.6	0.49	24	146	53	385	14	2.7	19.0	81.7	1.4
	2011	7.7	0.48	36	5	8	93	7	0.6	5.3	64.2	0.3
	2012	8.0	0.36	42	<1	7	13	2	0.1	7.0	65.1	0.3
	2014	7.3	0.03	47	101	38	NA	23	NA	13.1	189.5	1.2
	2015	7.8	0.21	53	11	3	32	2	0.9	1.9	10.7	0.1

Table 3- 9. Statistical results from the stepwise analysis of soils data and average tree volume index from 2008 to 2015 at the Birch River Mine reforestation plots in Webster County, West Virginia.

Species	Variable	P	R^2
All	Fines	0.0263	0.50
	Fe	0.0084	
	Mg	0.0105	
	Ca	0.0005	
BL	Fines	0.0026	0.32
	Fe	0.0045	
SM	Fines	0.0002	0.27
	Ca	0.0143	
WO	Fines	0.0008	0.26
	Ca	0.0024	
WP	Fines	0.0009	0.35
	Fe	0.0037	

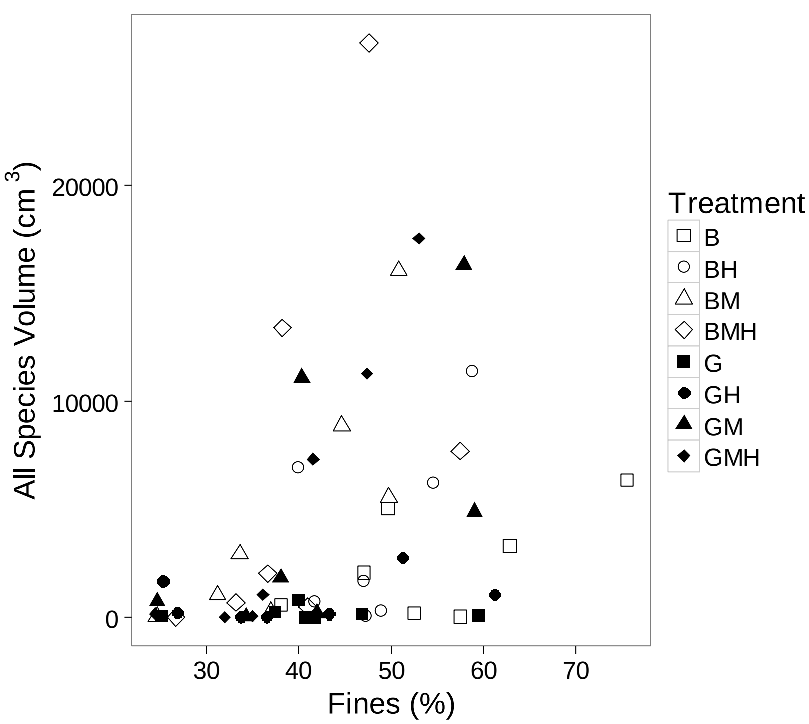

Figure 3-7. Relationship of percent fines and average volume index of all trees species combined over 9 years at the Birch River Mine reforestation plots in Webster County, West Virginia.

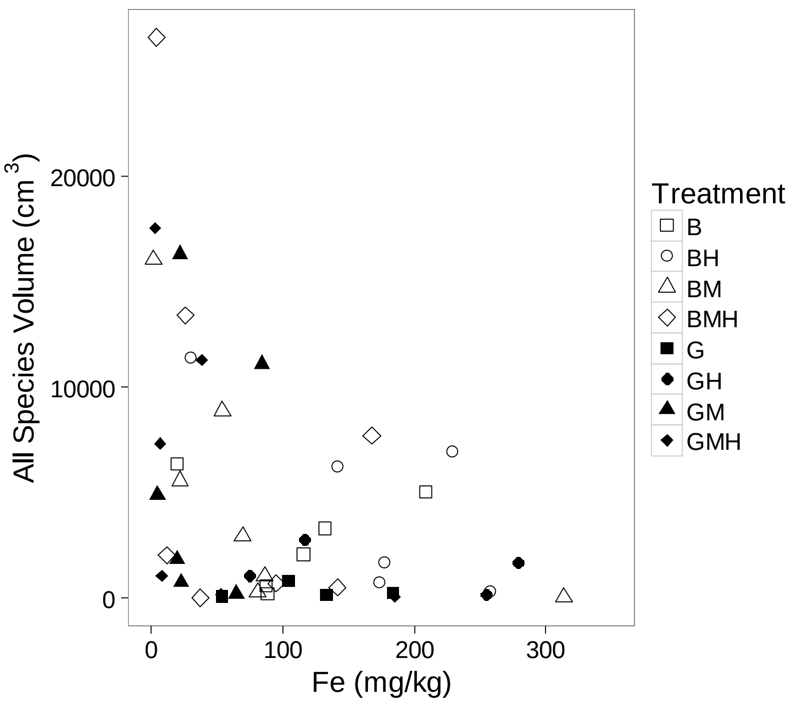

Figure 3-8. Relationship of average volume index of all tree species combined over nine years and iron at the Birch River Mine reforestation plots in Webster County, West Virginia.

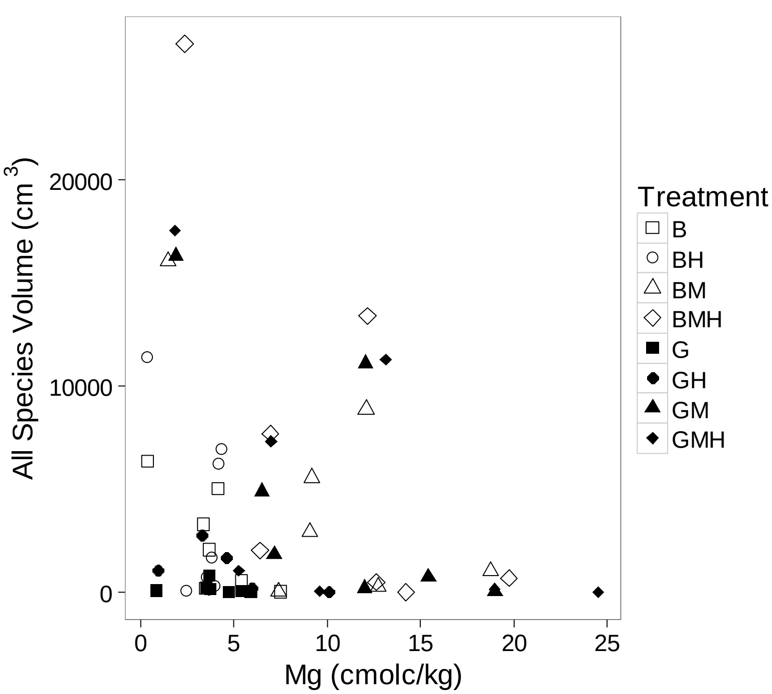

Figure 3-9. Relationship of average volume index of all trees species combined over 9 years to magnesium at the Birch River Mine reforestation plots in Webster County, West Virginia.

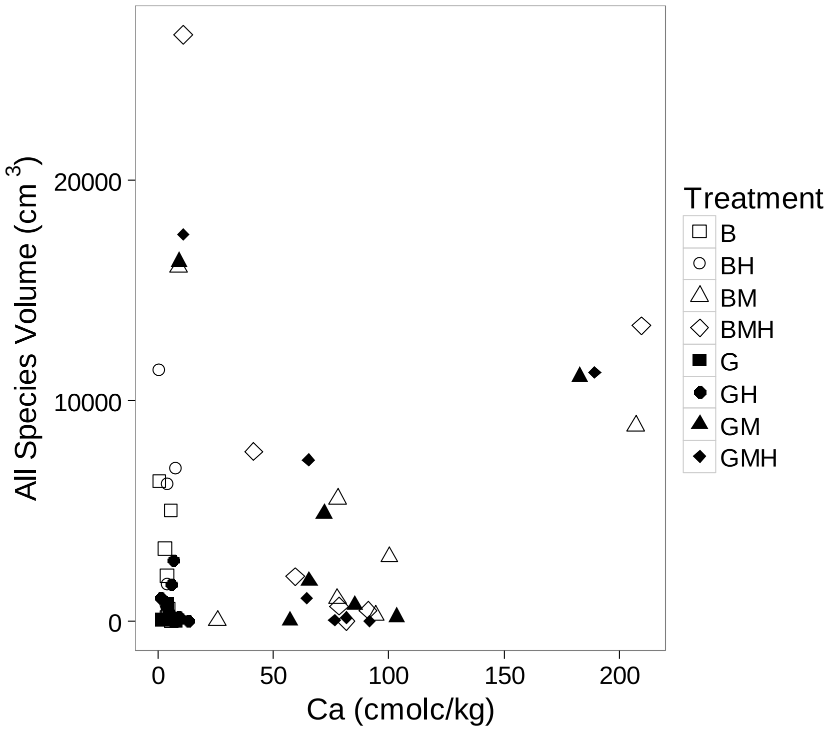

Figure 3-10. Relationship of average volume index of all tree species combined over 9 years to calcium at the Birch River Mine reforestation plots in Webster County, West Virginia.

3.4 Conclusion

When reforesting coal mine sites, the first step to successful tree growth is to have an appropriate growing medium. Brown sandstone was found to be a suitable topsoil replacement medium for tree growth. However, in the Appalachian region sometimes less desirable growing media, such as gray sandstone, is all that is available as reclamation growth media materials. This study demonstrated that even poor growing media can be improved by the addition of mulch and hydroseeding treatments. In order for successful reforestation of coal mines, amendments to the growing medium can accelerate tree growth regardless of the type of sandstone. Tree species selection is also important as different species grow better on different growing media. Black locust showed better growth than any other planted trees on these sites, and increased its density due to prolific seed recruitment and root sprouting. Sugar maple has been found to have low survival and growth on mine sites. White oak grows well on loose, acidic soils and is therefore well suited to brown sandstone. White pine has also been found to have good growth are mine soils and is considered a good reclamation species. Over the nine years of this project, soil properties showed high variation in values across treatments and within treatment plots. While the step wise regression selected percent fines, Fe, Mg, and Ca as being correlated to tree growth, the R^2 values were quite low. However, it is still certain that brown sandstone was preferred over gray sandstone and that gray sandstone should only be used if it is properly amended. Successful coal mine reclamation in the Appalachians should be supported by the use of a proper growing medium, such as uncompacted brown sandstone.

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4.0 Release of Nutrients from Weathering in Mine Soils of Different Ages

4.1 Literature Review

Weathering is defined as a biochemical process involving destruction and synthesis. Physical disintegration breaks down rocks into smaller rocks (eventually into sand and silt particles) without changing the composition or mineralogy. Chemical weathering generally involves water and its influence on changes in mineral composition, releasing soluble materials and synthesizing new materials. These soluble materials recombine into new (secondary) minerals, and released nutrients can be leached out with water or may be taken up by plants (Brady and Weil, 2002). As primary minerals are weathered into secondary minerals, the elements that comprise the minerals are often released (Roberts et al., 2005).

Overburden materials located closer to the surface are partially weathered in place and are more oxidized, leached, and acidic due to the loss of soluble carbonates and iron oxidation. Since they are located in oxidizing environments, these materials have undergone more extensive physical and chemical weathering. Modern mining techniques result in overburden from deeper depths in the geological column being brought to the surface, where they experience rapid weathering and leaching reactions. These unweathered overburden materials tend to have higher rock fragments, coarser textures, and higher pH until they have been weathered over long time periods (Haering et al., 2004).

After placement during reclamation, spoil materials will be altered by physical, chemical, and biological weathering (Daniels and Amos, 1985). The unoxidized overburden materials, such as gray sandstone, may develop properties conducive to reforestation as they are weathered over time. These fresh unweathered overburden materials placed on the surface may have greater levels of nutrients and exchangeable bases, which have not been removed as a result of weathering. With weathering, high concentrations may be released for uptake by plants or may be leached to deeper depths in the soil, or may be removed with runoff. Unweathered sandstone was found to be more resistant to weathering than brown sandstone (Miller et al., 2012) and therefore the release of nutrients may occur for decades. In a study by Haering et al. (1993), pH was found to decrease and then increase six years after reclamation in overburden materials consisting of sandstone, siltstone, or a combination of both. Fresh overburden materials contain complex carbonates that can become readily available upon exposure to weathering. The production of acids during organic matter oxidation, A horizon formation, and nitrogen fertilizer reactions were also thought to cause the initial decrease in pH. As these reactions slowed and weathering continued, more carbonates were released causing the pH to increase by year six. Levels of calcium (Ca) and magnesium (Mg) were also found to initially decrease and then increase by year 6. Potassium (K) and aluminum (Al) levels did not change much over the study. Iron (Fe) levels increased by year six.

Rapid changes were found in mine soil properties after three years of reclamation, including decreases in sand content, pH, and extractable Ca and Mg (Roberts et al., 1988). These rapid changes occurred as a result of active pedogenic processes on fresh geological materials. The processes are dissolution and leaching, oxidation, organic matter incorporation/decomposition, and shrink/swell and freeze/thaw which rapidly transform surface properties of mine soils in a relatively short time (Roberts et al., 1988).

The weathering of primary minerals will influence the nutrient status of soil. Weathering rates are controlled by environmental factors and the forms of primary minerals present (Sposito, 2008; Wilson, 2004). Primary silicates release sodium (Na), Mg, K, Ca, manganese (Mn), Fe, copper (Cu), and zinc (Zn) ions as they are weathered and they become bioavailable upon release (Sposito, 2008). Primary minerals that can be commonly found in mine soils in the Appalachian region include mica, kaolinite, quartz, and feldspar (Daniels and Stewart, 2000; Kingsbury, 1993; Miller et al., 2012). Micas are 2:1 silicate minerals and are the most important natural source of K in soils (Fanning and Keremidas, 1977). Kaolinites are 1:1 layer structured alumino-silicates mostly occupied by Al ions (Dixon, 1977). Quartz is mainly composed of silicon and oxygen but trace quantities of Al, Fe, Ca, K, and Mg are also common (Wilding et al., 1977). Feldspars are anhydrous alumino-silicates which contain varying amounts of Na, K, and Ca, and sometimes trace amounts of Cu (Huang, 1977). Ca, Na, and K ions are commonly released as feldspars are weathered (Brady and Weil, 2002; Dixon et al., 1982 (as cited in Kingsbury, 1993)).

The rates at which cations are released from the weathering of primary and secondary rates is important in understanding the fertility of forest soils (Kolka et al., 1996). Nutrient release rates are related to the mass of the clay fraction (Kolka et al., 1996) and the availability of water has also been found to be a primary mechanism for the rate of weathering of clay minerals (Folkoff and Meentemeyer, 1987).

The mineral constituents of soils provide large stores of Ca, Mg, and K in forests. Cation exchange and mineral weathering reactions in the soil provide a large amount of the nutrients needed for tree growth. Because of the interface between atmospheric, hydrologic, biologic, and geologic processes that occur at the surface in soils, mineral breakdown can occur rapidly as these interacting processes influence weathering rates. Minerals containing Mg, Fe, and Ca that are formed at high temperatures generally weather more easily than those formed at low temperature containing K, Na, silicon (Si), and Al. Climate, precipitation, soil temperature, soil water content and chemistry, pH, vegetation, and grain size also play an important role in determining mineral weathering rates (April and Newton, 1992). Organic matter also provides a large source of nutrients in soil and as forests develop and organic matter cycling increases, the amounts of available nutrients also increase.

Trace elements can be found in different forms in soils. The movement and fate of trace and heavy metals is controlled by their chemical, physical, and biological behavior. Metals can be found in soils in solution, sorbed to solid phases, or as part of the structure of solid phases. The solid phase usually includes the majority of metals found within soils. Metal concentrations in soils are dictated by the types of elements in the rocks, weathering rates, organic matter content, soil texture, and soil depth. Metals can exist in several forms and their release and retention are affected by the following components (Brown et al., 1999):

- identity of the metal;
- oxidation state of the metal;
- associations and complexes to solids and dissolved species (surface complexes, metal-lignan bonds, surface precipitates); and,
- molecular geometry and coordination environment of the metal.

The mobility, transport, and partitioning of trace elements are dependent on the chemical form and the processes are controlled by the physicochemical and biological characteristics of the soil system. Speciation of elements can vary over time and space because of the dissipation and flux of energy and materials involved in these biogeochemical processes. Speciation of an element refers to its occurrence in or distribution around different chemical species. Analysis of a chemical species is performed to identify or quantify one or more species of an element present in a sample.

Species is defined as an element in a specific and unique molecular, electronic, or nuclear structure (Hlavay et al., 2004).

Elements exist in a variety of settings in soils, which affects their release, transport and fate. Water soluble elements are mobile and plant available, and easily removed by plant uptake or soil leaching. Weakly adsorbed elements retained on the solid surface by weak electrostatic interaction or elements that can be released by ion exchange processes are part of the exchangeable/non-specifically-sorbed fraction. Only a small portion of elements are found in this fraction within soils. The specifically-sorbed fraction contains those elements that are less readily exchangeable because they are bound by covalent forces. Elements associated with organic complexes are part of the organic complex fraction (Rao et al., 2008). Trace elements exist in natural soils as mostly immobile species in silicates, aluminates, and other primary minerals and, as weathering occurs, will be released gradually to become more mobile and available to plants (Lopez-Sanchez et al., 2002).

Information on elemental concentrations in soils and their sorption to soil surfaces, as well as their potential mobility in soils, can be evaluated through sequential extraction (Rao et al., 2008; Sutherland, 2010). The use of selected chemicals as extractants of elements from solid phases gives information about the solubility, release and movement of these elements under the conditions imposed by the extractant to the soil. Extractants can vary from water and weak acids or bases to organic compounds and strong acids and bases. Elements released by each extractant can be roughly correlated to a specific fraction by which they are held in the soil. Limitations to sequential extraction include the lack of specificity in element removal, re-adsorption and subsequent redistribution among phases, lack of comparability between studies, potential for increased contamination with the number of extractant steps, and the length of time required to process successive steps. Sequential extractions are still useful because of the detailed information they provide on the origin, mode of occurrence, biological and physiochemical availability, mobilization, and transport of trace elements (Sutherland, 2010).

One common sequential extraction procedure is the method proposed by the Community Bureau of Reference (BCR), which was developed by the European Commission Testing Program in 1993 as an attempt to harmonize extraction procedures. The BCR method has undergone several improvements with the latest published in 1998. The optimized BCR method has three operationally defined steps: acid extractable, reducible, and oxidizable elemental phases. Precision and accuracy of the optimized BCR procedure can be increased by strictly adhering to the protocol. Common deviations that can affect precision and accuracy are moisture correction, sample mass, centrifugation specifics, shaking specifics, and incorporation of filtration (Sutherland, 2010). The optimized BCR procedure is currently the only procedure that is harmonized and standardized with available reference materials (Rao et al., 2008; Sutherland and Tack, 2003). This results in a significant advantage for the optimized BCR procedure over other sequential extraction procedures (Sutherland and Tack, 2003). The optimized BCR method has been used to assess changes in element speciation over time (Pueyo et al., 2008).

Digesting soil samples in aqua regia (concentrated nitric and hydrochloric acids in a 3:1 ratio), as recommended in the optimized BCR procedure, can give an estimate of the maximum amount of elements that are potentially solubilized with changing environmental conditions and complete breakdown of the mineral. Studies have shown the optimized BCR method to be repeatable and reproducible when applied to element distribution (Rao et al., 2008).

A study by Sutherland and Tack (2002) found that the optimized BCR procedure was precise for Al, Cu, Fe, Mn, lead (Pb), and Zn in all fractions, while fraction-specific accuracy was acceptable for Cu, Pb, and Zn. Mossop and Davidson (2003) found that the optimized BCR procedure was able to extract more Fe and Cu over the BCR procedure but did not change the amount of Mn and Zn extracted.

Brown sandstone is the preferred topsoil substitute and its benefit to the development of forest ecosystems is well known. However, little information is available on the long term favorability of brown sandstone and if it over time will continue to have soil properties desirable for tree growth. There is also little information on how gray sandstone weathers over time and if gray sandstone will become more favorable to tree growth as it is weathered. This study was established to evaluate nutrient release from brown and gray sandstone over time. The objectives were to:

- Determine if available nutrients in brown and gray sandstones increase over time;
- Determine if gray sandstone releases more available nutrients (due to being less weathered) over time than brown sandstone;

- Determine if available nutrients in brown and gray sandstone reach the same levels of forested soils over time;
- Determine if soil physical and chemical properties in brown and gray sandstone change over time; and;
- Determine if soil physical and chemical properties in brown and gray sandstone are comparable to forest soil conditions over time.

4.2 Materials and Methods

4.2.1 Sample Collection

Soil samples were collected from mined sites reclaimed with brown and gray sandstone of varying ages from mine sites in Webster County. Gray and brown sandstone samples were collected from the following locations:

- The Mynu area which was mined in the 1960's (45 years old);
- The Bear Pen area which was mined in the late 1970's (20 years old); and,
- From the Birch River reforestation plots, which were established in 2007 (9 years old and described in Chapter 3).

In addition, soil samples were also collected from an undisturbed, forested area. Site descriptions, which included slope, aspect, and dominant vegetation, were completed at each site (Table 4-1). Site locations are shown on Map 4-1. Personnel at the Birch River mine site who were familiar with the history of the area and mining practices assisted with locating the older sites. In general, since brown sandstone was removed first in older "shoot and shove" mining methods, it was assumed that brown sandstone would be found further from the wall since it would be the first material pushed from the surface downslope, while gray sandstone would be found closer to the highwall. Ten samples were randomly collected from each site at a depth of 0-15 cm. Soil samples were air dried and sieved with a 2-mm plastic sieve. Three samples from each site were used for the laboratory analysis.

4.2.2 BCR Sequential Extraction

The optimized 3-step BCR procedure was used (Rauret et al., 1999). One gram of each soil sample was oven dried at 105^{0}C to constant mass which was applied to all analytical values. A total of four different solutions were used during the extraction process. Solution 1 was 0.11 mol/L acetic acid, Solution 2 was 0.5 mol/L hydroxylamine hydrochloride, Solution 2 was 8.8 mol/L hydrogen peroxide, and Solution 4 was 1.0 mol/L ammonium acetate.

Table 4-1. Site descriptions for Mynu, Bear Pen, Reforestation Plots, and Forested area in Webster County, West Virginia to evaluate the release of nutrients in mine soils over time.

Site	Approximate Age	Sandstone	Site description
Mynu Area	45	Gray	Less than 2% slope Vegetation: silver maple, birch, tulip poplar, goldenrod, oak seedlings, ash
		Brown	2 to 5% slope Vegetation: black birch, hemlock, sugar maple, red maple, tulip poplar, ferns, American beech, red oak, sourwood
Bear Pen	20	Gray	2 to 5% slope Vegetation: Black locust, multiflora rose, grasses, Autumn olive
		Brown	Vegetation: Black birch, ferns, grasses, mosses, goldenrod, lespedeza,
Reforestation Plots	9	Gray	Less than 2% slope Vegetation: red oak, white pine, black locust; low herbaceous cover
		Brown	Less than 2% slope Vegetation: red oak, black locust, white pine, white oak, Rubus, mosses
Forested	NA	NA	20% Slope, SW Aspect Vegetation: Recently clearcut, Rubus, greenbrier, Solidago, deer tongue, red maple seedlings,

Step 1:

A 1 g sample of soil was weighed and 40 ml of Solution 1 was added to a 50-ml centrifuge tube. The tube was shaken for 16 hours at 160 rpm. The extract was separated from the solid residue by centrifugation for 20 min and the supernatant liquid was decanted into a polyethylene container. The residue was then washed with 20 ml of distilled water, shaken for 15 min, and centrifuged for 20 min at 3000 g.

Step 2:

Forty ml of Solution 2 was added to the residue from step 1 in the centrifuge tube. The centrifuge tube was manually shaken to re-suspend the residue and then shaken at 160 rpm for 16 hours. The same extraction and decantation procedure as in step 1 was followed. The residue was washed as in Step 1.

Step 3:

Ten ml of solution 3 was added to the residue from Step 2 in small aliquots to avoid losses from a possible violent reaction. The centrifuge tube was covered and allowed to digest at room temperature for 1 hour and was occasionally manually shaken. Next, the tube was placed in a water-bath at $85^{o}C$ for 1 hour. The volume was reduced to less than 3 ml by heating the centrifuge tube (uncovered). Ten ml of solution 3 was added to the centrifuge tube and covered. The centrifuge was placed in the water-bath at $85^{o}C$ for 1 hour. The cover was removed and the centrifuge heated until about 1 ml of liquid remained. Fifty ml of solution 4 was added to the residue and shaken for 16 hours at 160 rpm. The extract was separated by centrifugation for 20 min and the liquid decanted into a polyethylene container.

In addition, the residue from Step 3, as well as original soil material, was digested with aqua regia using a CEM microwave digester. This step served as an internal check. The pH of each soil sample was determined with a 1:1 mixture of 5 g of soil and 5 ml of DDI water. The 1:1 mixture was shaken at 120 oscillations per minute for one hour and then pH was measured with a Fisher Scientific Accument pH meter model 915 (Thermo Fisher Scientific Inc. Pittsburgh, PA). Each extract was analyzed for P, K, S, Ca, Mg, Mn, Cu, Zn, Al, and Fe using an ICP-OES (Inductively Coupled Plasma-Optical Emission Spectrometer Perkin-Elmer Corp. DV 2100, Norwalk, CT).

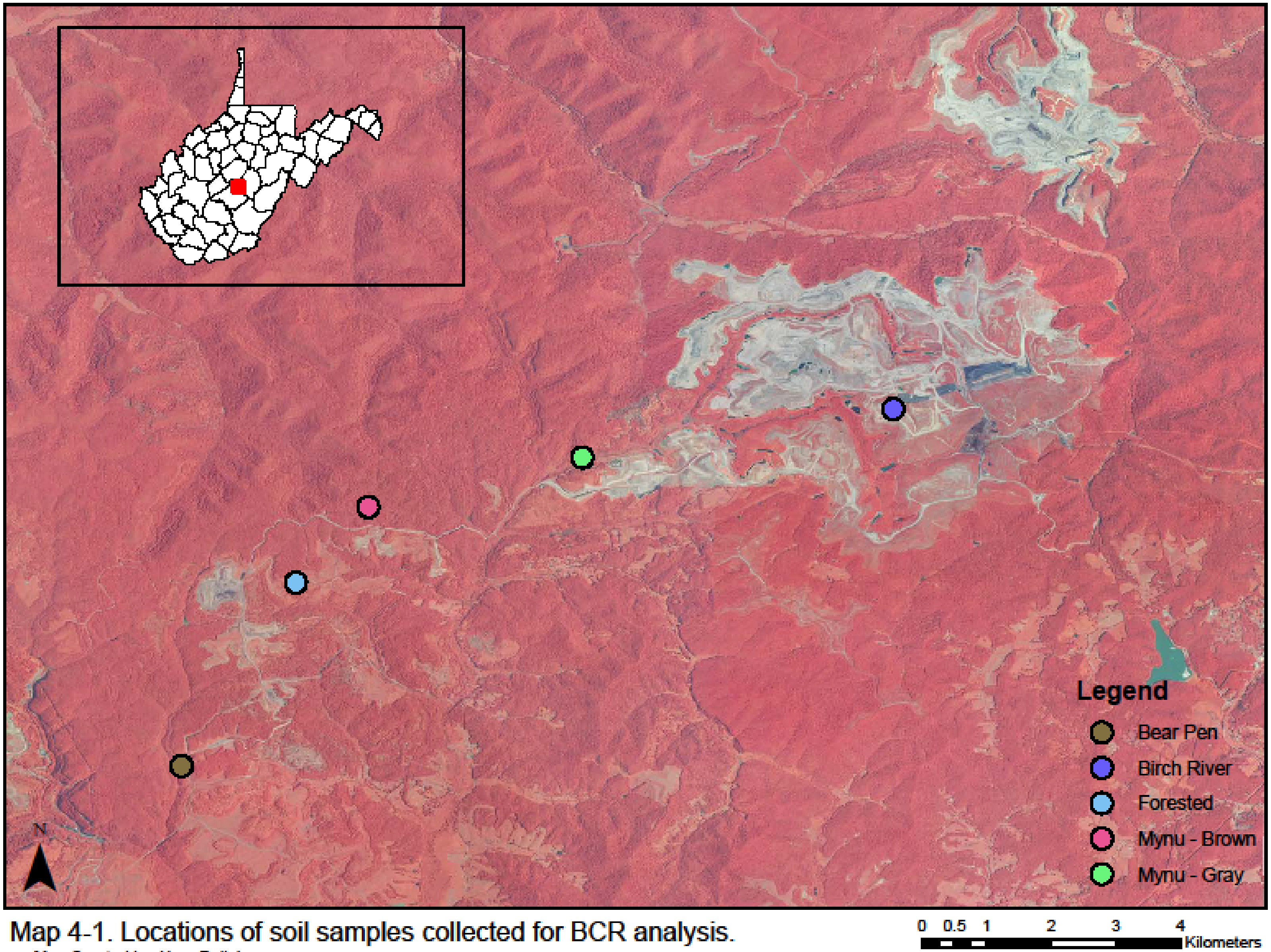
4.2.3 Total Digestion:

For the aqua regia digestion, 0.5 g of each soil sample was added to a Teflon vessel. A total of 9 ml of nitric acid and 3 ml of hydrochloric acid was added to each sample and samples were then left overnight to pre-digest under the fume hood. Samples were then digested with a Mars Express microwave (CEM, Matthews, North Carolina). The samples reached a temperature of 175^0C which was held constant for 20 minutes. After digestion, samples were diluted to 50 ml and filtered.

4.2.4 Soil Organic Matter:

Soil organic matter was determined by loss on ignition. Crucibles were heated to 400^0C for 2 hours in a muffle furnace and then weighed. One to 3 g of air-dried soil less than 0.4 mm particle size was added to each crucible. Crucibles were heated to 105^0C for 24 hours and then cooled in a calcium chloride desiccator. The weight of the oven dried crucibles was obtained. Samples were then placed in muffle furnace and heated to 400^0C for 16 hours and then cooled in a desiccator over calcium chloride. The weight of each crucible was determined. The loss on ignition content of the sample was then determined by the following equation:

$$\text{LOI, \%} = \frac{\text{Weight}_{105} - \text{Weight}_{400}}{\text{Weight}_{105}}$$



Map 4-1. Locations of soil samples collected for BCR analysis.
Map Created by: Kara Dallaire
Image Source: WV GIS Tech Center

4.2.5 Particle Size Distribution:

Ten grams of each sample was weighed into 250 ml centrifuge bottles. To remove carbonates, approximately 100 ml of water and 10 mL of 1 M NaOAc (adjusted to pH 5) were added to each bottle. Samples were centrifuged for 10 minutes at 1500 rpm until the supernatant was clear and then poured off. Each sample was washed twice by adding 50 ml of water, centrifuging, and then discarding the water.

Iron oxides were then removed by adding 40 ml of 0.3M sodium citrate and 5 ml of 0.5M sodium bicarbonate. This solution was heated to 80^{0}C in a water bath. One gram of sodium dithionite was added to the heated solution and the solution was stirred constantly for one minute and occasionally for 15 minutes. Ten ml of saturated sodium chloride and 10 ml of acetone were then added to each sample. The samples were centrifuged for 15 minutes and the supernatant was discarded. This procedure was completed twice for each sample to ensure that all the iron oxides were removed.

Five ml of 10% sodium hexametaphosphate was added to each sample and the bottles were each filled half way with distilled water. After shaking overnight, each sample was brought to 400 ml with distilled water. Each sample was stirred for two minutes. Since the temperature was 28^{0}C, the samples settled for 3 hours and 14 minutes. After the settling period, a 5-ml pipette was inserted 5 cm into each sample to remove a 2-µm particle fraction and the aliquot was transferred to a tarred crucible. The remaining sample was transferred to a 300-mesh (50 µm) sieve to separate the silt and clay. The sand was transferred to a beaker. The crucibles containing the clay fraction and the beakers containing the sand fraction were dried overnight at 105^{0}C and then weighed.

4.2.6 Statistical Analysis

Results from the first three steps were added together and labelled as “available.” Results from the total digestion step of the extraction were labelled as “residual.” An analysis of variance was also completed to determine if they were any differences between the different ages of brown and gray sandstone and the forested soils. Results were considered significant when the P value was less than 0.05. Differences among means were computed with Tukey’s Honestly Significant Difference test.

4.3 Results

For this study, it was assumed that gray and brown sandstone would have the same amount of total nutrients (residual and available) but that gray sandstone would initially have lower available nutrients as most of the nutrients would still be tied up in the residual phase. As the sandstone aged and weathered, it was thought that the amount of available nutrients would increase in both brown and gray sandstone but that the increase in gray sandstone would be greater.

Based on ANOVA, all the elements were found to be significantly different among different ages of brown and gray sandstone and the forest soil (Table 4-2). Table 4-3 shows the percent of available elements for all the sites. Figures 4-1 to 4-9 show the distribution and means of the data used in the ANOVA analysis.

Table 4-2. ANOVA results for available elements on sites reclaimed with brown and gray sandstone and from a forested area in Webster County, West Virginia. Significant differences were found for sites with $P < 0.05$.

Element	DF	Sum of Squares	F Value	P > F
P	6	3769	27.33	**<0.001**
K	6	84	18.52	**<0.001**
Ca	6	12533	4.62	**0.008**
Mg	6	6663	102	**<0.001**
Mn	6	5357	3.92	**0.017**
Cu	6	15802	29.9	**<0.001**
Zn	6	2654	3.59	**0.023**
Al	6	4450	46.77	**<0.001**
Fe	6	1201	18.34	**<0.001**

Table 4-3. Average available elements on different-aged sites reclaimed with brown and gray sandstone and from a forested area in Webster County, West Virginia.

Age	Sandstone	Available P	Available K	Available Ca	Available Mg	Available Mn	Available Cu	Available Zn	Available Al	Available Fe
		------------	------------	------------	------------	%	------------	------------	------------	------------
9	Gray	31^{b} [1]	2^{b}	37^{bc}	10^{cd}	80^{ab}	30^{bc}	38^{ab}	4^{d}	10^{bc}
	Brown	34^{b}	2^{b}	41^{c}	6^{d}	67^{ab}	43^{b}	33^{b}	6^{d}	3^{c}
20	Gray	61^{a}	5^{a}	100^{a}	60^{a}	93^{a}	94^{a}	68^{a}	30^{bc}	24^{a}
	Brown	56^{a}	6^{a}	98^{ab}	32^{b}	89^{a}	13^{cd}	56^{ab}	34^{ab}	14^{b}
45	Gray	23^{b}	2^{b}	55^{abc}	17^{c}	74^{ab}	25^{bcd}	54^{ab}	7^{d}	14^{b}
	Brown	50^{a}	2^{b}	44^{abc}	9^{cd}	46^{b}	72^{bcd}	80^{ab}	20^{c}	9^{bc}
Forest	Forest	53^{a}	7^{a}	62^{abc}	33^{b}	95^{a}	2^{d}	54^{ab}	45^{a}	26^{a}

[1]Means with the same letters for elements in columns are not significantly different at $P < 0.05$.

Figure 4-1 is a boxplot for available P. For the brown and gray sandstone, the highest available P occurred at age 20 which was higher than the forest soil. Available P decreased significantly in gray sandstone from age 20 to 45. The decrease was much less for brown sandstone and at age 45 and the available P for brown sandstone was comparable to the forest soil.

The boxplot for available K, is shown in Figure 4-2, but note the much lower % available than for P and other elements. The highest available K occurred in the forest soil. Brown and gray sandstone had comparable amounts of available K at all ages and an increase was seen at age 20 and then a decrease at age 45. K is usually released quickly during weathering so it was expected that the brown and gray sandstone would have higher amounts of available K than the forest soil, but this was not the case.

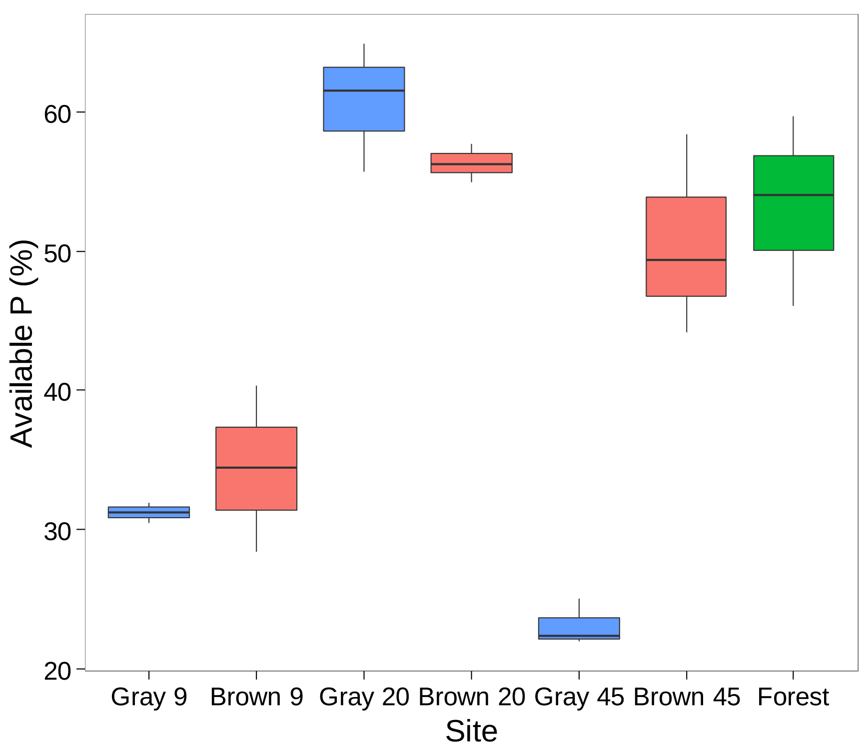


Figure 4-1. Boxplot of percent available phosphorus on sites reclaimed with brown and gray sandstone and from a forested area in Webster County, West Virginia. Black lines within boxes represent the mean available P, the boxes represent the upper and lower quartile, and vertical lines extending from boxes represent the inner quartile.

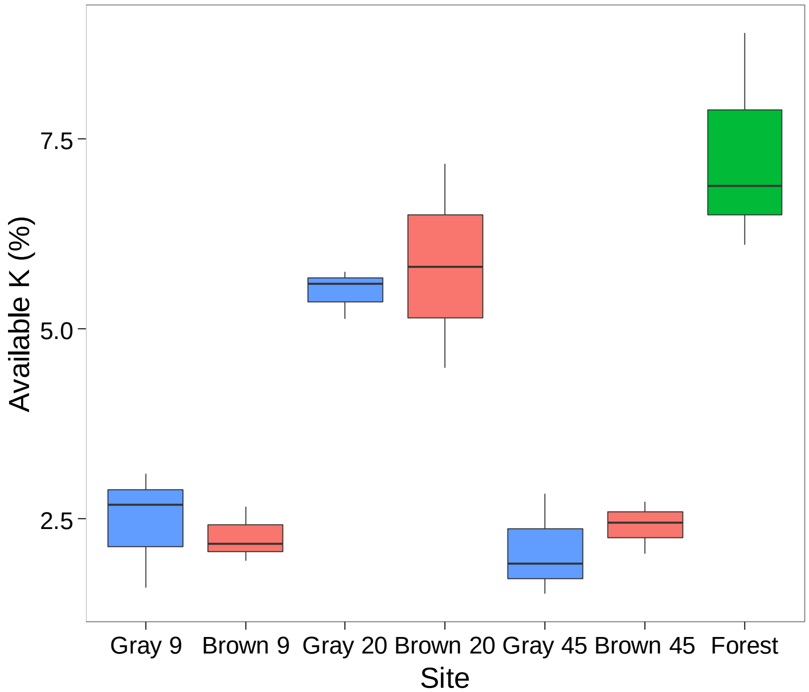


Figure 4-2. Boxplot of percent available potassium on sites reclaimed with brown and gray sandstone and from a forested area in Webster County, West Virginia. Black lines within boxes represent the mean available potassium, the boxes represent the upper and lower quartile, and vertical lines extending from boxes represent the inner quartile.

Figure 4-3 shows the boxplot for available Ca and shows that brown and gray sandstone at age 20 had the highest available Ca, which essentially doubled from age 9 to age 20. There was a decrease at age 45 for brown and gray sandstone, however, both the brown and gray sandstone means were within the range of values of the forest soil.

For available Mg, the box plot in Figure 4-4 shows that the highest amount occurred in gray sandstone at age 20. Brown sandstone had the highest availability of Mg at age 20, which was similar to the forest soil. From age 20 to age 45, available Mg decreased in both brown and gray sandstone to amounts lower than the forested site but higher than at age 9.

Average Mn availability was higher in the forested soil than the brown and gray sandstone (Figure 4-5). At age 20, both the brown and gray sandstone had an average Mn availability similar to the forest soil. Average Mn availability decreased at age 45 and was lower than the forest soil.

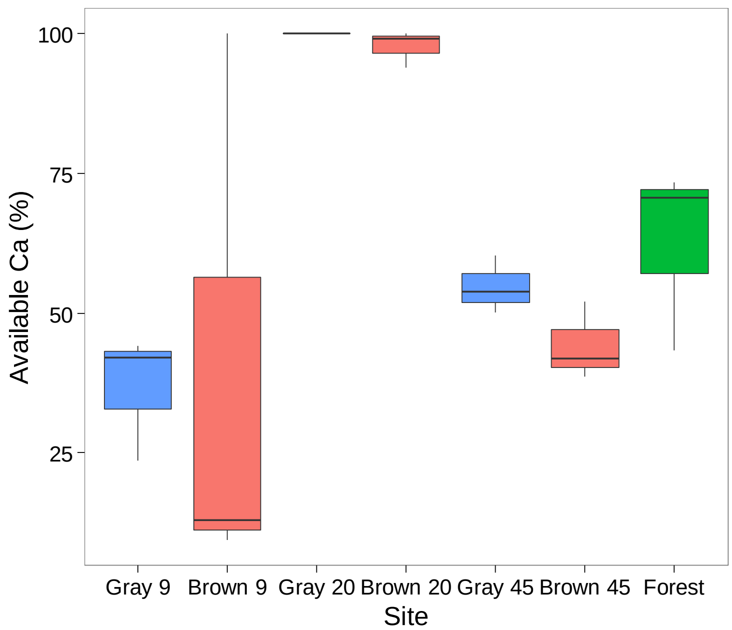


Figure 4-3. Boxplot of percent available calcium on sites reclaimed with brown and gray sandstone and from a forested area in Webster County, West Virginia. Black lines within boxes represent the mean available calcium, the boxes represent the upper and lower quartile, and vertical lines extending from boxes represent the inner quartile.

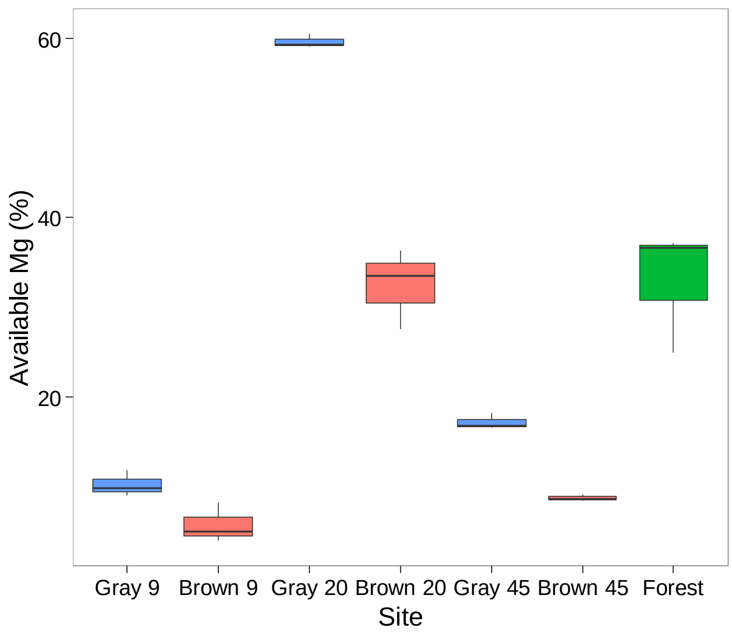


Figure 4-4. Boxplot of percent available magnesium on sites reclaimed with brown and gray sandstone and from a forested area in Webster County, WV. Black lines within boxes represent the mean available magnesium, the boxes represent the upper and lower quartile, and vertical lines extending from boxes represent the inner quartile.

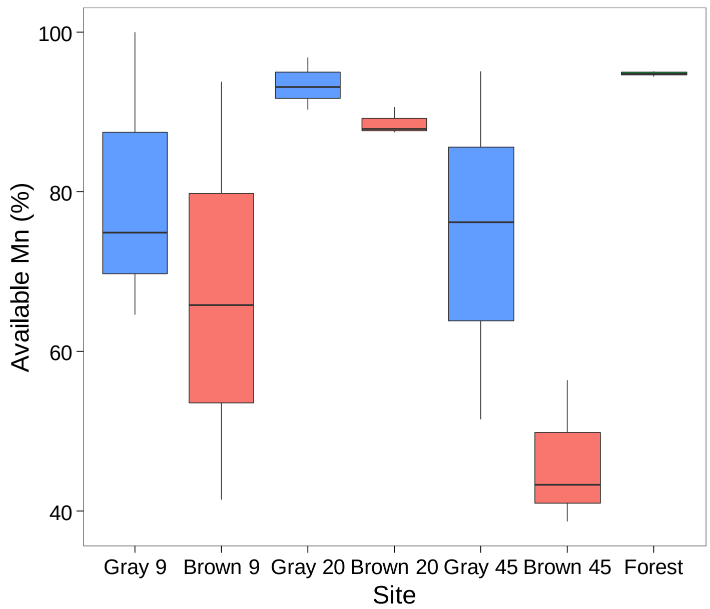


Figure 4-5. Boxplot of percent available manganese on sites reclaimed with brown and gray sandstone and from a forested area in Webster County, West Virginia. Black lines within boxes represent the mean available manganese, the boxes represent the upper and lower quartile, and vertical lines extending from boxes represent the inner quartile.

Available Cu was the only element to have the lowest amounts in the forest (Figure 4-6). For brown sandstone, the highest amount of available Cu was found in the age 9 sites. For gray sandstone, the age 20 site had the highest amount of Cu.

Figure 4-7 shows the boxplot for available Zn. Age 20 of brown and gray sandstone had the highest average available Zn. Available Zn decreased for brown and gray at age 45 but amounts are higher than at age 9.

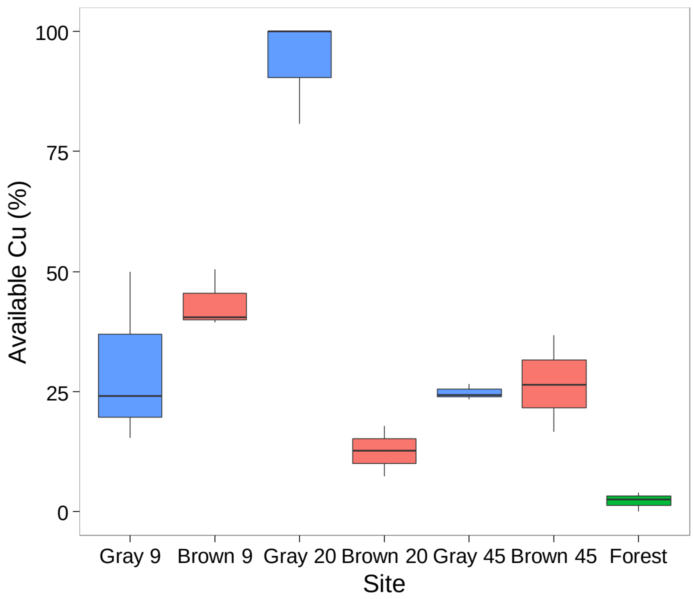


Figure 4-6. Boxplot of percent available copper on sites reclaimed with brown and gray sandstone and from a forested area in Webster County, West Virginia. Black lines within boxes represent the mean available copper, the boxes represent the upper and lower quartile, and vertical lines extending from boxes represent the inner quartile.

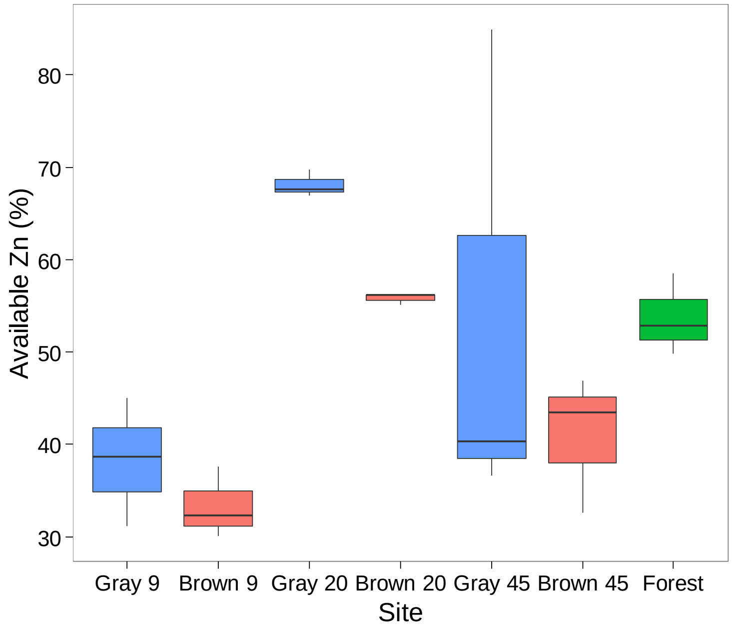


Figure 4-7. Boxplot of percent available zinc on sites reclaimed with brown and gray sandstone and from a forested area in Webster County, West Virginia. Black lines within boxes represent the mean available zinc, the boxes represent the upper and lower quartile, and vertical lines extending from boxes represent the inner quartile.

Both available Al and Fe were higher in the forest than in the brown and gray sandstone (Figure 4-8 and 4-9). Age 20 had the highest average Al and Fe availability for both brown and gray sandstone. As with the other elements, there was an increase at age 20 and then a decrease at age 45 for brown and gray sandstone. Brown sandstone had higher Al availability at all ages than gray sandstone. Gray sandstone had higher Fe availability at all ages than brown sandstone.

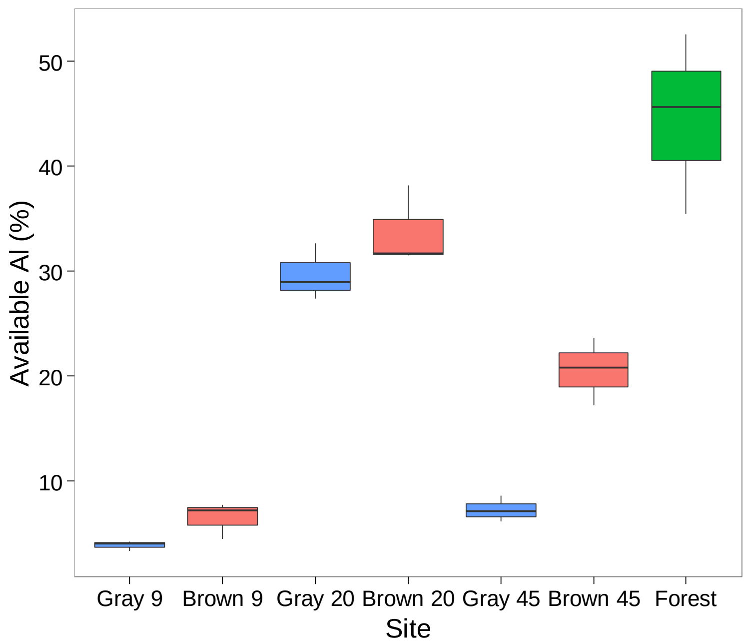


Figure 4-8. Boxplot of percent available aluminum on sites reclaimed with brown and gray sandstone and from a forested area in Webster County, West Virginia. Black lines within boxes represent the mean available aluminum, the boxes represent the upper and lower quartile, and vertical lines extending from boxes represent the inner quartile.

Table 4-4 shows that organic matter, pH, EC, percent fines, percent sand, and percent clay were also found to be significantly different among different ages of brown and gray sandstone and in the forest soil. In addition to mineral weathering, pH, OM, and particle size also influence nutrient availability in the soil.

Figure 4-10 shows the boxplot for organic matter. Organic matter content of brown and gray sandstone increased with age and, at age 45, the amount was similar in both sandstones to the forest soil. OM is important for nutrient cycling and an increase over time is an indication of the quality of the mine soils improving with age.

Figure 4-10 shows that the highest pH occurred in gray sandstone at age 9. The pH of gray sandstone is commonly higher than in brown sandstone (Angel et al., 2008; Emerson et al., 2009; Haering et al., 2004; Sena et al., 2014; Showalter et al., 2009; Wilson-Kokes, 20013a and 2013b) and these results were expected. At age 45, the pH of gray sandstone was comparable to the pH of the forest soil. The pH of the brown sandstone was similar to the forest at all ages. Figure 4-11 shows the boxplot for EC. Except for gray sandstone at age 45, EC values for brown and gray sandstone were lower in the brown and gray sandstone than in the forest soil. While EC was found to be significantly different, all EC values were too low to have any negative effect on tree growth.

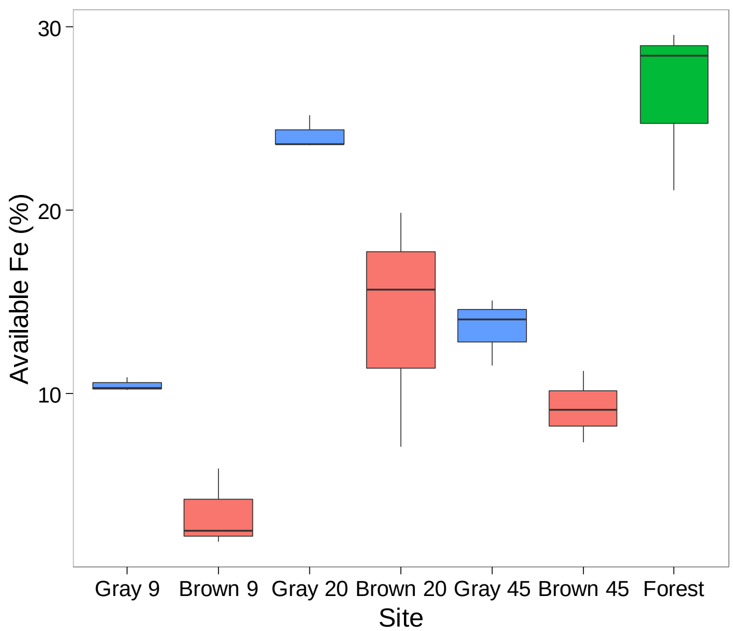


Figure 4-9. Boxplot of percent available iron on sites reclaimed with brown and gray sandstone and from a forested area in Webster County, West Virginia. Black lines within boxes represent the mean available iron, the boxes represent the upper and lower quartile, and vertical lines extending from boxes represent the inner quartile.

Table 4-4. ANOVA results for soil properties on sites reclaimed with brown and gray sandstone and from a forested area in Webster County, West Virginia.

Property	DF	Sum of Squares	F Value	P> F
OM	6	15	8.19	**<0.001**
pH	6	16	12.21	**<0.001**
EC	6	0.01	9.45	**<0.001**
Fines	6	4588	6.21	**0.002**
Sand	6	4581	3.68	**0.02**
Silt	6	1104	1.06	0.43
Clay	6	1306	16.78	**<0.001**

Table 4-5. Average soil properties on sites reclaimed with brown and gray sandstone and from a forested area in Webster County, West Virginia.

Age	Sandstone	OM	pH	EC	Fines	Sand	Silt	Clay
		--%--		-dS m^{-1}-	----------------------	----------%----------	----------	----------
9	Gray	0.30$^{d\ 1}$	6.5^{a}	0.03^{c}	54^{bc}	68^{a}	19^{a}	13^{e}
	Brown	0.33^{d}	4.2^{b}	0.03^{c}	64^{abc}	55^{ab}	23^{a}	22^{cde}
20	Gray	0.43^{cd}	6.1^{a}	0.05^{c}	48^{bc}	65^{ab}	20^{a}	15de
	Brown	0.80^{bcd}	4.5^{b}	0.05^{bc}	43^{c}	51^{ab}	26^{a}	23^{bcd}
45	Gray	2.00^{ab}	4.2^{b}	0.10^{a}	56^{bc}	31^{ab}	33^{a}	35^{a}
	Brown	2.45^{a}	4.7^{b}	0.04^{c}	75^{ab}	47^{ab}	26^{a}	28^{abc}
Forest		1.90^{abc}	4.6^{b}	0.09^{ab}	88^{a}	26^{b}	41^{a}	33^{ab}

[1]Means with the same letters for elements in columns are not significantly different at P <0.05.

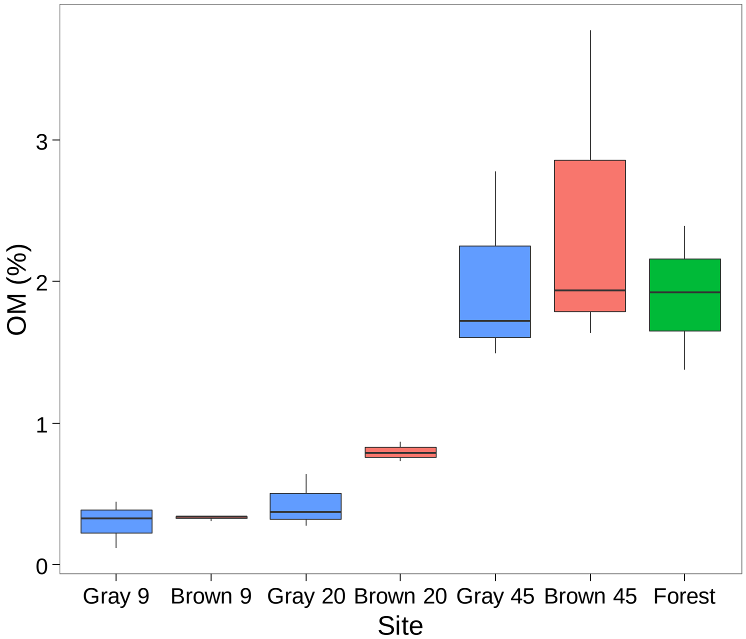


Figure 4-10. Boxplot of organic matter on sites reclaimed with brown and gray sandstone and from a forested area in Webster County, West Virginia. Black lines within boxes represent the mean organic matter content, the boxes represent the upper and lower quartile, and vertical lines extending from boxes represent the inner quartile.

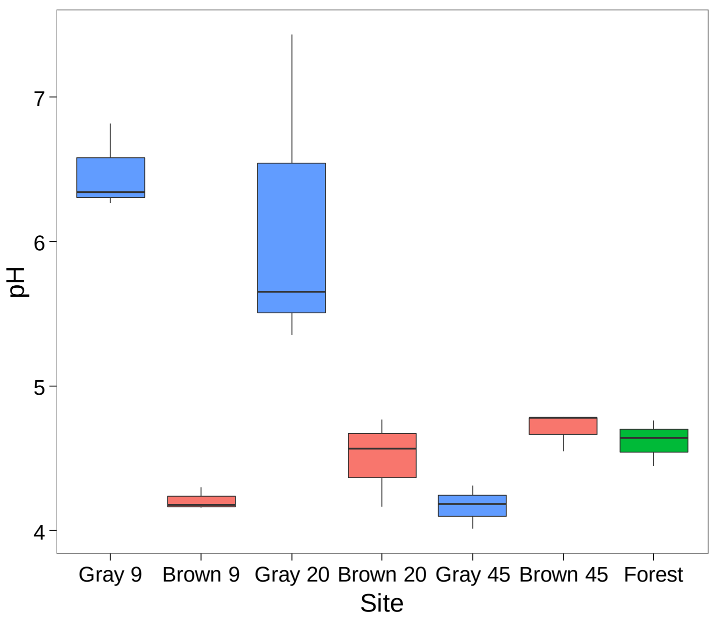


Figure 4-11. Boxplot of pH on sites reclaimed with brown and gray sandstone and from a forested area in Webster County, West Virginia. Black lines within boxes represent the mean pH, the boxes represent the upper and lower quartile, and vertical lines extending from boxes represent the inner quartile.

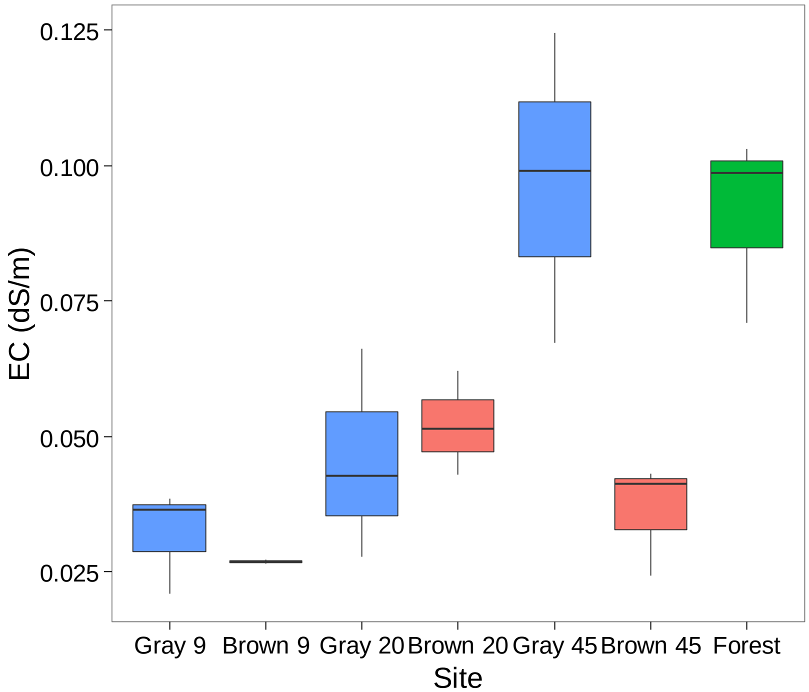


Figure 4-12. Boxplot of electrical conductivity on sites reclaimed with brown and gray sandstone and from a forested area in Webster County, West Virginia. Black lines within boxes represent the mean electrical conductivity, the boxes represent the upper and lower quartile, and vertical lines extending from boxes represent the inner quartile. Individual points not on the vertical lines or within the boxes are considered outliers.

Percent fines were higher in the forest than in any age of brown and gray sandstone (Figure 4-13). For particle size distributions, the finer fractions (clay and silt) were higher in the forest soil, while sand was lower in the forest soil (Figure 4-14 to 4-16).

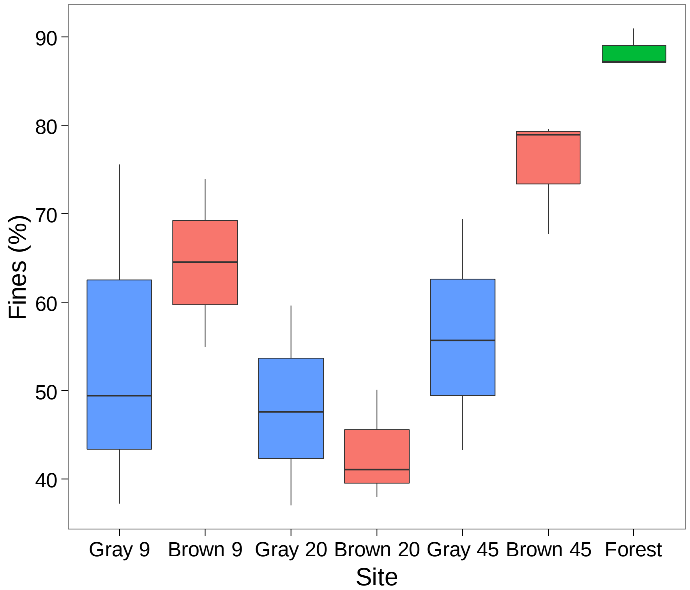


Figure 4-13. Boxplot of percent fines on sites reclaimed with brown and gray sandstone and from a forested area in Webster County, West Virginia. Black lines within boxes represent the mean fines content, the boxes represent the upper and lower quartile, and vertical lines extending from boxes represent the inner quartile.

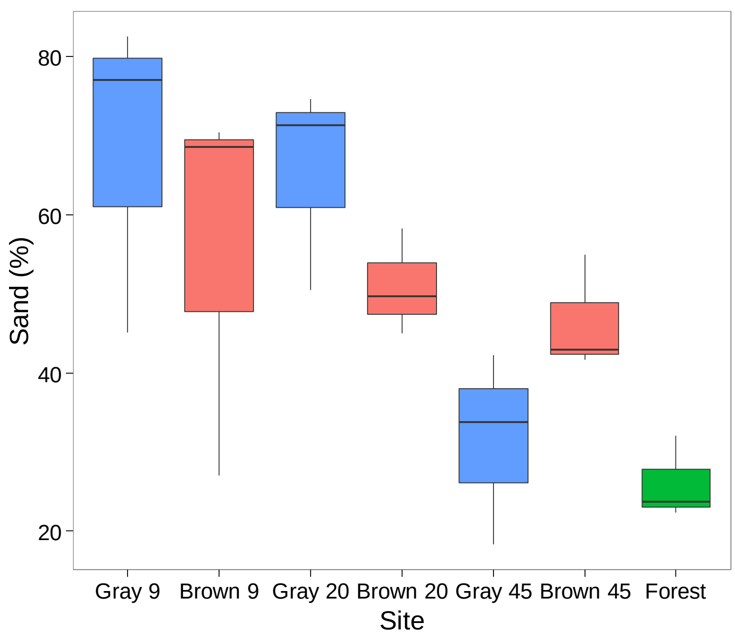


Figure 4-14. Boxplot of percent sand on sites reclaimed with brown and gray sandstone and from a forested area in Webster County, West Virginia. Black lines within boxes represent the mean sand content, the boxes represent the upper and lower quartile, and vertical lines extending from boxes represent the inner quartile.

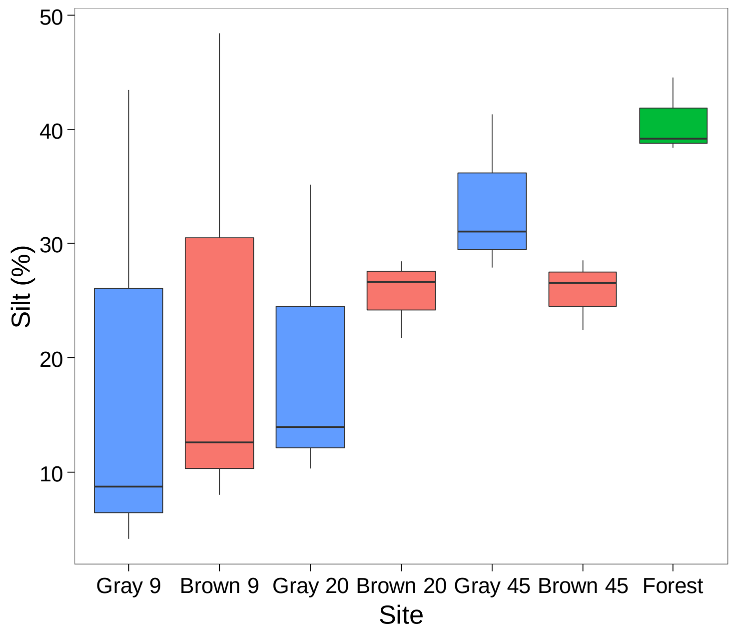


Figure 4-15. Boxplot of percent silt on sites reclaimed with brown and gray sandstone and from a forested area in Webster County, West Virginia. Black lines within boxes represent the mean silt content, the boxes represent the upper and lower quartile, and vertical lines extending from boxes represent the inner quartile.

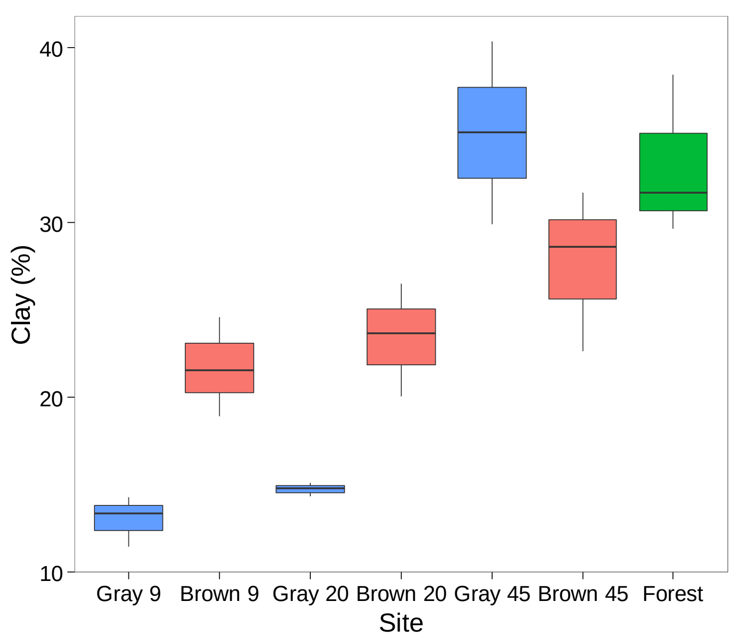


Figure 4-16. Boxplot of percent clay on sites reclaimed with brown and gray sandstone and from a forested area in Webster County, West Virginia. Black lines within boxes represent the mean clay content, the boxes represent the upper and lower quartile, and vertical lines extending from boxes represent the inner quartile.

It was thought that significant differences in nutrient availability would be found with time of weathering and that the older reclaimed sites (specifically the gray sandstone sites) would have more nutrients in the “available” form than the “residual” form. However, we did not find this to be the case. Further, we expected that gray and brown mine soils would release elements at different rates as they aged. But our data showed otherwise. Some studies reported finding no differences of available nutrients between gray and brown sandstone. Emerson (2008) found that there were no significant differences between gray and brown sandstone for Mg, Ca, K, and P when using the Morgan extraction method after only 2 years of weathering, but both materials were freshly placed and undergoing rapid weathering reactions and changes so those changes were still too recent to be measured. The Morgan extraction solution is a weak extractant composed of 10% sodium acetate and 3% acetic acid and extracted only the weakly sorbed elements on soil surfaces.

The availability of most nutrients has been shown to be inversely related to the pH of a soil (Havlin et al., 1999). The average pH of gray sandstone at age 9 and 20 were the highest but even this high pH level of 8 is within the pH limits when most elements are available. All elements except Cu were lower in the gray and brown sandstone than in the forest, but not always lower in the gray sandstone compared to the brown sandstone. The organic matter content of the forest soil was higher than the sandstones and organic matter cycling is known to influence nutrient availability and cycling. As both pH and OM affect nutrient cycling so much, the lowering of pH and the increase of OM in the mine soils as they age could indicate that the mine soils are returning to pre-mining conditions with concomitant increases in nutrient availability with age and weathering.

At age 20, both the brown and gray sandstone showed an increase of the “available” fraction of elements and then a decrease at age 45. Possible reasons for the increase at age 20 was that nutrients were being released through weathering as the brown and gray sandstone aged (as was predicted), as well as the low nutrient demand from the aboveground vegetation as the forest vegetation was only beginning to develop. The decrease in nutrients from age 20 to 45 was possibly be due to higher nutrient demand and uptake by vegetation, increased organic matter content could increase the number of exchange sites that sorb elements making them unavailable, higher organic matter contents in aging soils would also promote a microbial community with demands for nutrient use, and to immobilization of nutrients as secondary minerals form.

Errors during this experiment could have occurred during the laboratory procedures. The BCR extraction is a four-step procedure and errors could have occurred at each step, thereby magnifying errors with each step. For example, at each step there is some loss of sample during centrifuging, decanting the liquid, and washing the sample before the next step. Other errors can occur if elements are redistributed among solid phases during extractions, with complexation reactions decreasing and changing the measured available fraction (Rodgers et al., 2015).

4.4 Conclusion

While it is well known that brown sandstone provides a more suitable growing medium for trees than gray sandstone at the initial stages of reclamation, little information is available on the long term potentials of brown and gray sandstone as they age and weather. As mineral weathering occurs, nutrients are released into the soil and it was initially thought that available nutrients would increase as mine soils aged. However, no linear correlation was found between age of mine soil and amount of nutrient available, but there was a strong effect of age with the youngest and oldest sites being lower than the middle-aged site. Significant differences were found when comparing the amount of available nutrients in the brown and gray sandstone to the forest. Nutrient availability was found to be highest at age 20 for both brown and gray sandstone. For P, Cu, Mg, and Zn, nutrient availability at age 20 was found to be higher or similar to nutrient availability in the forest. As nutrient availability and soil physical and chemical properties are all important to the growth of trees, the fact that the data showed similar properties in the brown and gray sandstone and in the forest provided evidence that the brown and gray sandstone can be as productive as the forest soil for tree growth.

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5.0 Height of Tree Hardwood Species Growing on Mine Sites Reclaimed Using the Forestry Reclamation Approach Compared to Natural Conditions.

This chapter is a reprint of a paper that was reviewed, accepted and published in the Journal of the American Society of Mining and Reclamation with the following reference:

Dallaire, K., J. Skousen, and J. Schuler. 2015. Height of three hardwood species growing on mine sites reclaimed using the forestry reclamation approach compared to natural conditions. J. Am. Soc. Mining Recl. 4: 20-31.

Abstract: Coal is an important source of energy for electricity and is used to make steel and various other products. West Virginia is the largest coal producing state within the Appalachian region. Surface mining of coal drastically disturbs ecologically diverse forests and the reforestation of these areas after mining is an important first step to helping restore their ecosystem functions. After mining, operators are often left with brown and gray sandstone to use as topsoil substitutes. Brown sandstone has been more weathered and has physical and chemical properties that are better for tree growth (lower pH, higher percent fines, higher available nutrients) than gray sandstone. Two study sites were established on former mine sites in West Virginia to assess the effects of brown and gray sandstone, with and without mulch treatments, on tree establishment. Tree growth data for tulip poplar (*Liriodendron tulipifera* L.), white oak (*Quercus alba* L.) and northern red oak (*Q. rubra* L.).), as well as soil samples (analyzed for pH, EC, percent fines, and extractable nutrients) have been collected annually for the last 10 years. The pH of brown sandstone was 5.2 to 5.4, gray sandstone was 6.5 to 6.8, and mulch treatments were 7.0. Percent fines ranged from 42 to 60% on all treatments. The mulch treatment had high levels of Ca (197 $cmol_c$/kg). The height growth of each tree species on both mine sites was compared to the growth of trees growing on clear-cut areas at the Fernow Forest, WV. In addition, an estimated site index prior to disturbance was calculated and used to predict tree growth rates based on NRCS soil survey data. Tree heights (25 to 175 cm) on gray sandstone were significantly lower than height on brown sandstone (197 to 544 cm) for all three species. Trees on mulched plots were up to 229 cm taller than trees on un-mulched plots. Tulip poplar height on the brown treatment (544 cm) was greater than on a clear-cut area with a site index 62 at 10 years (503 cm). Tree heights on average were 50% lower on mined sites compared to heights calculated from pre-mining site indices.

5.1 Literature Review

Coal is an important source of energy and is used to make steel and various other products (Bise, 2013). There are more than 100 minable coal seems within the Appalachian region and West Virginia is the largest coal producing state within this region (Bise, 2013; U.S. EIA, 2013). In 2012, West Virginia had 104 active surface mines that produced over 36 million Mg of coal (U.S. EIA, 2013). Approximately 78% of West Virginia is covered in valuable eastern deciduous forests and surface mining drastically disturbs these ecologically diverse forests. Reforestation of mined lands is important because forests provide important benefits to society including wood and fiber production, watershed and hydrologic values, wildlife habitat, carbon sequestration, and ecosystem stability (Burger, 1999).

The first surface mining legislation in West Virginia was enacted in 1939 (Bowling, 1978; Plass, 2000). Revegetation of all surface mine spoils was required and specific reclamation laws were established. Many hectares of mined land were successfully reclaimed to forest plantations; however, enforcement of these laws was difficult and large areas remained unreclaimed. As developments in mining equipment were made, the area disturbed for surface mining increased. Public concern of the effects of mining on human safety and the environment increased as the total area disturbed by mining grew (Plass, 2000). The Surface Mining Control and Reclamation Act (SMCRA) was enacted in 1977 by the federal government to address safety and environmental issues and caused a major change in reclamation practices (Burger, 1999; Skousen and Zipper, 2013 and 2014). Under SMCRA, selected overburden materials are allowed to be substituted for topsoil when the substituted material is at least as equally sustaining to vegetation as the topsoil. Mass stability of slopes was required under SMCRA which encouraged excessive grading and smoothing of reclaimed land (Skousen and Zipper, 2014). The establishment of a grass and legume cover was required on all disturbances. Fertilizer and liming treatments became accepted mine land reclamation treatments because they improved the growth of the ground cover crops. Reforestation had been previously an important reclamation strategy for mined lands, but the new reclamation requirements shifted the emphasis for revegetation from trees to herbaceous covers. With this emphasis of ground cover for erosion control, these herbaceous cover crops caused severe competition with tree seedlings on compacted soils, resulting in low tree survival, and tree planting decreased. As a result, fewer mined areas were returned to forested lands (Plass, 2000), fewer trees naturally re-colonized reclaimed mined sites, and the loss of Appalachian forests has been ongoing since the enactment of SMCRA (Zipper et al., 2011).

The Appalachian Regional Reforestation Initiative (ARRI) was created to encourage restoration of high quality forests on reclaimed mines in the Eastern USA (Angel et al., 2005). ARRI developed the Forestry Reclamation Approach (FRA) to encourage reclaiming coal mines to forests under SMCRA (Burger et al., 2005). The following five steps are recommended:

1. Create a suitable rooting medium for good tree growth that is no less than 1.2 m deep and comprised of topsoil, weathered sandstone and/or the best materials.
2. Loosely grade the topsoil or topsoil substitute established in step one to create a non-compacted growth medium.
3. Use ground covers that are compatible with growing trees.
4. Plant early successional trees for wildlife and soil stability, and commercially valuable trees.
5. Use proper tree planting techniques.

Due to the steep terrain, it is often not possible to collect and save the topsoil in West Virginia and other Appalachian regions. Weathered, brown sandstones and unweathered, gray sandstones that are exposed during mining are commonly used as substitute topsoil materials. Brown sandstone is found closer to the surface and typically has a pH ranging from 4.0 to 5.5 due to oxidizing conditions (Haering et al., 2004). In addition, brown sandstones have low electrical conductivity (EC), moderately acidic pH, and high percentages of fines (<2 mm); all correlated with increased tree growth (Daniels and Amos, 1985; Rodrigue and Burger, 2004). Gray sandstone is found underneath brown sandstone and it was not oxidized by weathering processes. The pH of gray sandstone ranges from 7.5 to 8.0 (Haering et al., 2004; Emerson et al., 2009). The weathered, brown sandstone is the preferred topsoil substitute in restoration of forest trees (Skousen et al., 2011). Numerous studies have shown that brown sandstone has superior tree growth over gray sandstone (Angel et al., 2008; Emerson et al., 2009; Sena et al., 2014; Showalter et al., 2010; Wilson-Kokes, et al., 20013a and 2013b).

Tree growth can be improved with amendments on reclaimed sites (Angel et al., 2006; Thomas and Skousen, 2011; Wilson-Kokes et al., 2013a). In a study by Angel et al. (2006), the addition of bark mulch improved the growth of two species on uncompacted plots on a reclaimed coal mine in eastern Kentucky. Wilson-Kokes et al. (2013b) found that adding bark mulch to both brown and gray sandstone increased the growth of hardwood species on a reclaimed coal mine in West Virginia. Another study in West Virginia, by Thomas and Skousen (2011) also found that tree growth was improved on both gray and brown sandstone when bark mulch was added.

Site index (SI) is usually defined as the total height of dominant and co-dominant trees at 50 years total age and can be used to estimate the site quality of a stand for a particular species. Site quality is an estimate of the relative productivity of forestlands and calculated from height measurements since the height growth of dominant and co-dominant trees is related to site quality in a fully stocked stand (Carmean et al., 1989). The rate of height growth is related to site quality (Carmean, 1975). When calculating SI for a stand, free growing, uninjured, dominant and co-dominant trees from a well-stocked, even-aged stand are used. SI curves are specific to species, geographic region, and the soil and/or topography (Carmean et al., 1975). SI is related to surface soil depth, subsoil texture, aspect, and slope position and steepness (Carmean, 1977). Higher SI are found on sites with favorable site conditions for growing trees. Mine soils may have lower SI due to their lower soil quality, particularly when gray sandstone is used.

The purpose of this paper was to compare the height growth of tulip poplar (*Liriodendron tulipifera* L.), white oak (*Quercus alba* L.) and northern red oak (*Q. rubra* L.) from two different mine sites, with different soil treatments, in West Virginia to the growth of the same species growing under undisturbed conditions. The undisturbed heights come from a forest that was clear-cut. In addition, pre-mine site index for each mine site was estimated using information from the NRCS Web Soil Survey to estimate heights of trees prior to mining.

5.2 Materials and Methods

Tree height data from two mine sites in West Virginia and a study site from the Fernow Experimental Forest were evaluated for this study. In addition, estimated pre-mine site indices for each of the mine sites was calculated from the NRCS Web Soil Survey. One mine site has two different soil treatments and the other has three different soil treatments. Table 1 lists all the study sites and treatments used and they are each described further below.

Table 5-1. Abbreviations used to describe all the treatments and studies used to compare tree growth on two reclaimed coal mines to tree growth in natural areas.

Treatment	Abbreviation
Birch River – brown sandstone[1]	BR-B
Birch River – gray sandstone	BR-G
Birch River – mulch	BR-M
Catenary – brown sandstone	C-B
Catenary – gray sandstone	C-G
Clear-cut with release – SI 62	CR-62
Clear-cut with release – SI 75	CR-75
Pre-mining – Birch River	PBR
Pre-mining – Catenary	PC

[1] Combined 1.2 and 1.5 m plots.

The first mine site is the Birch River mine, located in Webster County, and owned by Arch Coal (38°25'31.74"N, 80°36'39.74"W)) and was established in 2006. A 2.5-ha experimental plot was established to determine the effects of soil amendments on tree growth and survival on brown and gray sandstone. Half the plot was constructed with approximately 1.5 m of brown sandstone and the other half was constructed with approximately 1.5 m of gray sandstone. Plots were left uncompacted. Bark mulch was applied to the center of the plot over parts of both brown and gray sandstone plots. Eleven 2.7-m-wide transects that spanned the width of the plot were established. Yearly measurements of height and diameter at 2.5 cm have been made on all trees within these transects, except in 2013. Gray sandstone, brown sandstone, and the mulch treatment are the three treatments used from this site.

The second mine site is the Catenary mine, located in Kanawha, Raleigh, and Boone counties (38°5'28"N, 81°26'37"W) and was established in 2005. The Catenary Mine is owned by Patriot Coal and operated by Catenary Coal Company. Three plots were established with two plots being constructed of weathered brown sandstone on the surface, one with 1.5 m depth and the other with 1.2 m depth. The third plot was constructed by placing 1.5 m of unweathered gray sandstone on the surface. One half of each plot was considered "un-compacted" and received only one or two passes of the bulldozer, while the other half received several passes of the bulldozer and was considered "compacted." Two 2.7-m-wide by 195-m-long transects were established in an "X" pattern across each of the six treatments. Yearly measurements of height and diameter at 2.5 cm have been made on all trees within these transects have been measured yearly, except for 2010 and 2013.

A total of twelve tree species were planted at each site on 2.4 m centers. For the purposes of this paper, only tulip poplar (*Liriodendron tulipifera* L.), white oak (*Quercus alba* L.) and northern red oak (*Q. rubra* L.) are discussed.

Tree growth data from 2014 at the Birch River and Catenary sites were compared to data from a study from the Fernow Experimental Forest near Parsons, West Virginia (Smith, 1983; Trimble, 1973). The Fernow Forest has elevations ranging from 533 to 1113 m, annual precipitation of 147 cm, shallow soils derived from sandstone, shale, or limestone, and commercially important tree species (USDA, 2014a). The Fernow Experimental Forest was selected because site conditions are similar to those of the mine sites. The study by Smith (1983) measured heights of tulip poplar and northern red oak growing on two sites that had been clear-cut, one with a SI of 75 and the other with SI 62. The trees in this study were released from all competition each year. This study was chosen to show the rates of trees growing under ideal conditions (free from competition) for average and low site qualities.

In addition, the NRCS Web Soil Survey was accessed to estimate the forest productivity (SI) at each site prior to disturbance for each of the three species. The pre-mining SI for each mine site was determined by calculating a weighted average of SI listed for the site in the soil survey (Web Soil Survey). Once an average SI was calculated at each site for northern red oak, white oak, and tulip poplar, this number was used to estimate the height of trees each year up to the age of 12. In order to calculate the estimated heights for the younger trees, the formulation equation from Carmean et al. (1989) was used. The formulation equations is:

$$H = b_1 S^{b_2 (1-e^{b_3 A})\,\hat{}\, b_4 S^{b_5}}$$

H = Height

bi = Regression Parameters

S = Site Index

A = Age

The pre-mining SI at Birch River was 78 for both northern red oak and white oak, and 92 for tulip poplar (USDA, 2014b) (Table 2). At the Catenary mine, the SI for northern red oak was 78, while white oak and tulip poplar had higher SI at 85 and 95, respectively (USDA, 2014b) (Table 2).

Table 5-2. Pre-mining site indexes (SI) for northern red oak, white oak, and tulip poplar at the Birch River and Catenary mines in West Virginia.

Site	Northern red oak SI	White oak SI	Tulip poplar SI
Birch River	78	78	92
Catenary	78	85	95

5.3 Results and Discussion

Table 3 shows the pH, EC, and percent fines of the Birch River and Catenary mines from samples collected in 2014. The pH of the brown sandstone (BR-B and C-B) from both mine sites was within the typical range of weathered sandstone 4.5 to 5.5 (Emerson et al., 2009; Haering et al., 2004; Wilson-Kokes et al., 2013a and 2013b). Typically, unweathered sandstone from the Appalachian region has a higher pH (7.5 to 8.0) (Emerson et al., 2009; Haering et al., 2004; Wilson-Kokes et al., 2013a and 2013b) and the pH from both gray sandstone sites (BR-G and C-G) was lower. The average pH of the mulch treatment (BR-M) was the highest (7.0). Limestone gravel was added to the mulch as an aggregate at the sawmill and is likely the cause of the high pH. The pH of the pre-mining soils (PBR and PC) and the clear-cut soils (CC-62 and CC-75) was slightly more acidic than any of the mine soils (4.1-5.2) (NCSS, 2015). EC was very low, with the highest values being 0.04 dS/m on the mulch treatment (BR-M). Percent fines ranged from 42 to 60%, with no apparent difference between any treatments or sites.

Table 5-3. Soil properties (pH, EC, percent fines) of the Birch River and Catenary mine sites in 2014.

	Properties		
Treatment	pH	EC	Fines
		--dS m^{-1}---	--%--
BR-B	5.2	0.01	45
BR-G	6.5	0.01	49
BR-M	7.0	0.04	43
C-B	5.4	0.01	60
C-G	6.8	0.01	42
CC-62, CC-75	4.1-5.2	0.0	Unknown

PB	4.6-4.7	0.0	Unknown
PC	4.7-4.9	0.0	Unknown

Extractable nutrient information is reported in Table 4. Calcium, Mg, and P concentrations between gray and brown sandstone and between mine sites were similar. For the mulch treatment (BR-M), Ca concentration was much higher and Mg and K concentrations were slightly higher. Aluminum concentrations for gray sandstone and the mulch treatments were similar, while the concentration in the brown treatments was higher. Iron concentration was lowest in the mulch treatment (51 mg/kg in BR-M) and ranged from 126 to 219 mg/kg in the gray (BR-G and C-G) and brown (BR-G and C-G) treatments. The P concentration in Catenary gray sandstone (C-G) was much higher (180 mg/kg) than the other treatments (23 to 46 mg/kg). Mehlich 1 extractable nutrient information was not available for the clear-cut sites (CC_62 and CC-75) or the pre-disturbance soils (PBR and PC).

Table 5-4. Extractable nutrients (Ca, Mg, K, Al, Fe, P) from mine soil samples collected from the Birch River and Catenary mines in 2014.

	Element					
Treatment	Ca	K	Mg	Al	Fe	P
	------------------$cmol_c$/kg------------------			---------------------mg/kg------------------		
BR-B	6	0.6	4	402	219	38
BR-G	6	0.3	4	113	126	46
BR-M	197	12	12	115	51	23
S-B	7	0.6	5	431	154	41
S-G	10	0.4	5	150	149	180

The higher levels of Al found in the brown sandstone was likely due to the fact that brown sandstone had been exposed to more weathering than gray sandstone (Wilson-Kokes, 2013b). While the phosphorus concentration in the Catenary gray treatment was high (180 mg/kg), it was still within the range of other reported phosphorus levels in gray sandstone (Wilson-Kokes et al., 2013b). The high calcium concentration in the mulch treatment was also expected due to the incorporated limestone. Calcium has been shown to increase the growth of hardwood trees in poor soils (Bigelow and Canham, 2007).

Figure 1 compares the heights of northern red oak growing on the two mine sites, the two clear-cut sites (SI of 62 and 72), and the heights calculated from the pre-mining SI. From the graph, it is clear that tree growth was slow on gray sandstone at both mine sites, with both showing almost no growth at all. The Catenary reforestation study was established 2 years prior to the study at

Birch River, so the lines for Catenary extend to 10 yrs, while Birch River only extend to 8 yrs. The trees on brown sandstone (BR-B and C-B) were growing much faster than those on gray sandstone at both sites, but did not grow at rates equal to the pre-mining SI. The Birch River (BR-B) mine had higher growth rates than Catenary (C-B). The mulch treatment at Birch River (BR-M) slightly increased the overall height of northern red oak. The height of red oak at 8 yrs at both the BR-B and BR-M sites was close to the height of trees growing on the two clear-cut sites (CC-62 and CC-75). At age 8, the height of northern red oak on the Birch River (BR_B) mine (226 cm) was not the same as that predicted by the pre-mining SI (PBR) height (445 cm). At Catenary (C-B), the average height of northern red oak at age 10 (231 cm) was less than half that predicted by pre-mining SI (PC) height (570 cm).

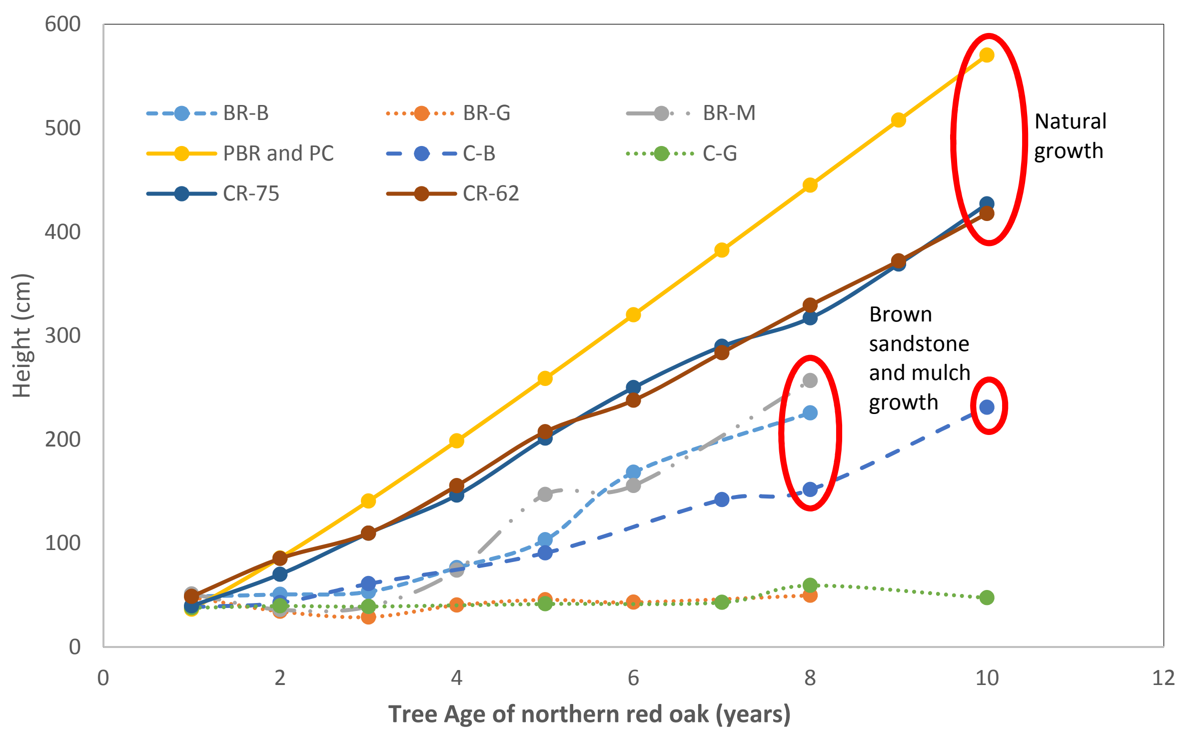

Figure 5-1. The height of northern red oak growing on two mine sites with different soil types, on two different clear-cut sites, and on estimated pre-mining site.

Figure 2 shows the height of white oak at the two reclaimed sites and the predicted heights from the pre-mining SI. As with northern red oak, white oak growing on gray sandstone (BR-G and C-G) were not very tall. The white oak on brown sandstone (BR-B and C-B) were taller and growing at faster rates than on gray, with the trees at Birch River grew faster than trees at Catenary. The mulch treatment (BR-M) at Birch River increased the height growth of white oak. White oak on mulch treatments (BR-M) was approximately 130 cm shorter (approximately 67%) than the predicted height for the pre-mining SI (PBR). The pre-mining SI at Catenary (PC) was higher than that at Birch River (PBR). The height difference of white oak between Catenary brown sandstone (C-B) was much lower (242 cm) than the predicted SI (PC) heights (641 cm) at age 10.

Figure 5-2. The height of white oak growing on two mine sites with different soil types, and on estimated pre-mining site conditions.

Figure 3 compares the height of tulip poplar growing on the reclaimed mines and clear-cut sites, as well as that predicted by pre-mining SI. Once again, height growth on gray sandstone (BR-G and C-G) was lowest. All tulip poplar heights were higher on the brown sandstone, but height growth at Catenary (C-B) was much lower than at Birch River (BR-B). The mulch treatment (BR-M) had the tallest trees at age 8 of all reclaimed mine sites. Tulip poplar height on the mulch treatment was even higher (494 cm) than tulip poplar on the SI clear-cut site (351 cm on CR-62). At age 10, the height of tulip poplar at Catenary (544 cm on C-B) was higher than on the clear-cut site with the lower SI (503 cm on CR-62). Tulip poplar heights on all mine site treatments were much lower than the pre-mining predicted SI (PBR and PC) heights at all ages.

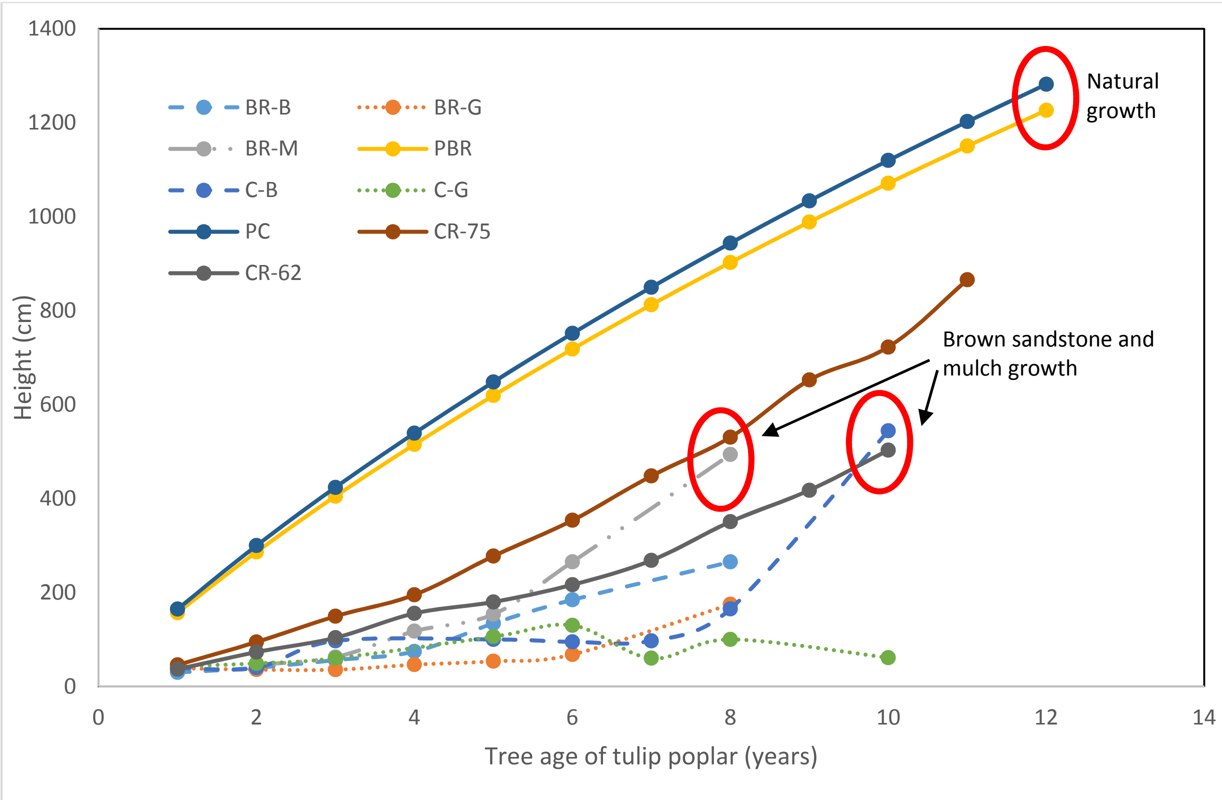

Figure 5-3. The height of tulip poplar growing on two mine sites with different soil types, on three different clear-cut sites, and on estimated pre-mining site conditions.

The tree species discussed in this paper were not growing as fast or as tall as trees in the estimated undisturbed soil conditions (based on the Web Soil Survey). It should be noted that the SI equation used to predict the expected growth of the trees up to 12 years is generally used for older trees. Most site index equations are less accurate when predicting height of younger trees (Carmean et al., 1989). Growth rates on poorer sites, such as reclaimed mine sites, will generally increase more slowly than higher quality sites but will maintain this growth for longer time periods (Beck and Trousdell, 1973). Assuming that the reclaimed sites are lower quality sites than the site conditions in the pre-mining forest, it would make sense that the growth is initially slow and may eventually reach the same rates as trees growing on the original site as the site matures and soils develop. Initial growth of trees can also be affected by factors other than site quality, such as competition from weeds, animal and insect damage, or differences in stock quality and planting techniques (Carmean, 1975).

The height of trees predicted by SI used in the paper was used to show that reclamation methods are producing trees, but the results show that the reclamation methods used at these sites have yet to produce growth rates similar to the original productivity of the site. Cotton et al. (2012) compared the growth of tulip poplar and white oak on a reclaimed coal mine in Kentucky to the growth of trees in reference forests and found that growth was less than half on mine sites reclaimed with conventional techniques. This study also emphasized that soil amendments on mine soils greatly improved the growth of trees. Other studies have also shown soil amendments on mine soils to improve the growth of trees (Angel et al., 2006; Conrad et al., 2008; Thomas and Skousen, 2011; Wilson-Kokes, et al., 2013a). A study by Burger and Fannon (2009) found that the SI for tulip poplar was much lower on reclaimed sites (56) than the weighted average pre-mine SI (82). Another study by Groninger et al. (2006) also found that site productivity on reclaimed surface mines in Indiana much below that of native forests in the same region.

5.4 Conclusions

Tree height on Catenary brown sandstone was lower than that on Birch River brown sandstone. The reason for this is unclear as there were no differences between any of the measured soil properties. For all three species, tree heights on gray sandstone (25 to 175 cm) were lower than tree height on brown sandstone (197 to 544 cm). Mulch treatment increased the growth up to 229 cm on both brown and gray mine soils. The 10-yr-old tulip poplar height on the brown treatment (544 cm) was greater than heights on the lower quality clear-cut area with a site index 62 (503 cm). Tree heights were lower on mined sites compared to heights on clear-cut sites and those calculated from pre-mining site indices, but mulching improved height growth of trees on mined sites.

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Appendix A: Vigor Ratings

Table A-1. Average vigor ratings for all tree species in 2015 at the Catenary Mine in West Virginia.

	Species[1]								
Treatment	BC	BL	RB	RO	SM	TP	WA	WO	WP
	------------------------Vigor Rating------------------------								
1.2BC	2.0	3.5	2.0	3.2	NA	4.0	3.0	4.5	NA
1.2BNC	3.0	3.1	3.5	4.5	4.0	3.5	3.9	4.5	NA
1.5BC	4.3	3.5	3.3	4.4	3.0	3.8	3.8	4.4	5.0
1.5BNC	5.0	3.5	NA	4.3	3.7	4.3	3.9	4.2	5.0
GC	4.0	4.0	2.7	3.0	2.0	2.5	2.3	3.0	3.8
GNC	NA	3.0	2.5	3.4	2.0	2.5	2.4	4.1	4.3

[1] BC = black cherry; BL = black locust; RB = redbud; RO = red oak; SM = sugar maple; TP = tulip poplar; WA = white ash; WO = white oak; WP = white pine

Table A-2. Average vigor ratings for all tree species in 2015 at the Birch River Mine in Webster County, WV.

	Species[1]									
Treatment	BC	BL	RB	RO	SM	SY	TP	WA	WO	WP
	--------------------------Vigor Rating--------------------------									
B	4.2	4.0	3.5	5.0	4.2	3.8	3.3	3.3	4.6	4.8
BH	3.1	3.4	NA	4.6	4.0	4.4	3.6	3.9	4.8	5.0
BM	NA	3.6	4.0	5.0	4.0	NA	3.8	3.0	5.0	5.0
BMH	2.0	3.8	4.0	4.7	4.0	4.5	3.8	2.0	4.0	5.0
G	3.7	3.0	NA	2.4	3.7	4.0	2.0	1.0	4.0	3.8
GH	3.0	3.5	3.0	4.0	3.6	4.0	NA	3.0	4.0	5.0
GM	3.0	3.8	NA	4.7	3.8	4.0	4.0	3.2	5.0	5.0
GMH	3.4	3.7	NA	5.0	4.0	4.5	3.0	5.0	4.0	4.8

1 BC = black cherry; BL = black locust; RB = redbud; RO = red oak; SM = sugar maple; SY = sycamore; TP = tulip poplar; WA = white ash; WO = white oak; WP = white pine